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(54) High precision photosolidification modelling device.

(57) A high-precision photo-solidification modeling device for forming a solidified image having a desired model shape by exposing to light a liquid capable of being solidified in receipt of the light in a region corresponding to the desired model shape. The modeling device includes an offset quantity computing device for computing a quantity of offsetting a contour of the exposure region to an inside of a three-dimensional contour plane of the desired model shape so as to make a three-dimensional contour plane of the solidified image contact with the three-dimensional contour plane of the desired model shape. Accordingly, the solidified image is prevented from being formed outside the contour of the desired model shape, thereby obtaining a solidified model of a desired shape.

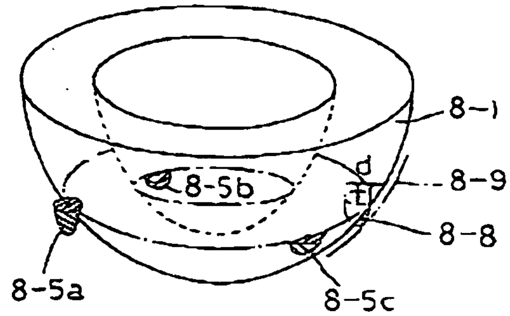


FIG. 8(B)

EP 0 484 182 A1

The present invention relates to an improvement in a high-precision photo-solidification modeling device for forming a solidified image having a desired model shape by exposing to light a liquid capable of being solidified when exposed to the light in a region corresponding to the desired model shape.

In recent years, there have been widely used a three-dimensional CAD for designing a three-dimensional shape with use of a computer and a three-dimensional measuring instrument such as a continuous tomographic system. It is becoming increasingly helpful to confirm directly and visually the three-dimensional shape on the basis of data relating to the three-dimensional shape created or measured by these systems. It is also increasingly necessary to easily fabricate a model having the three-dimensional shape in a short time on the basis of the above data.

Some previous techniques to satisfy these demands are disclosed in U.S. Patent No. 2,795,758 and Japanese Laid-open Patent Publication No. 56-144478.

According to the known techniques, there is provided a photo-solidification modeling device for forming a solidified image having a desired model shape by exposing to light a liquid capable of being solidified upon exposure to the light in a region corresponding to the desired model shape. In each technique, the solidified image is modeled as follows:

(1) A surface of the liquid is exposed to light in a region corresponding to one section of the desired model shape to form a section solidified image corresponding to this one section;

(2) Liquid for use in forming a further section is introduced onto the previously solidified image;

(3) A new surface of the liquid is exposed to light in a region corresponding to this further section to form a new solidified section on the previously solidified section; and

(4) The above steps are repeated for all the other sections to fabricate a three-dimensional solidified image as a laminated section solidified image.

As another technique, there has been proposed in Japanese Laid-open Patent Publication No. 60-247515 a technique of immersing a tip of an optical fiber into the liquid and moving the tip in the liquid in X, Y, and Z directions to thereby expose a region corresponding to the desired model shape to light.

There have been proposed some techniques of exposing only a region corresponding to a sectional shape on the liquid surface. For example, the following techniques are known:

(1) A technique of controllably moving a light beam in two horizontal directions (this technique including a control method of an angular coordinate type);

(2) A technique of controllably moving a light beam in one horizontal direction and moving a liquid in a direction perpendicular to the one horizontal direction; and

(3) A technique of entirely exposing a liquid surface covered with a mask film. As a modification, it is also proposed that the liquid surface is entirely scanned by sweeping a light source linearly arranged or using a slide projector, is employed to control an exposure region.

In the case that the exposure region is scanned by utilizing a light beam, the phenomenon shown in Figs. 8(A) and 8(B) must be considered. Referring to Fig. 8(A), a closed curve 8-1 denotes a contour of a desired model shape in one section. When a light beam 8-2 is moved in the direction of arrow 8-4 so that the center 8-3 of the light beam 8-2 follows the contour 8-1, a contour 8-5 of an actual exposure region is formed outside of the contour 8-1.

Fig. 8 (B) shows a three-dimensional view of Fig.8(A), wherein 8-5a, 8-5b, and 8-5c denote solidified regions that are formed at different positions by moving the light beam 8-2 along the contour 8-1. It is intended that the solidified image actually envelope all of the solidified regions 8-5a, 8-5b, 8-5c, etc., however, as can be seen, the regions 8-5a, 8-5b, and 8-5c extend in part outside of the contour 8-1 of the desired model shape.

In a photo-solidification modeling device practically used at present, the above-mentioned problem is solved by offsetting the center 8-3 of the light beam 8-2 to a position 8-6 inside of the contour 8-1 of the desired model shape as shown in Fig. 8(A) (normally, the center 8-3 of the light beam 8-2 is offset inside by a radius d of the light beam 8-2), and moving the light beam 8-2 in a direction of arrow 8-7 along the contour 8-1.

However, there still remains a problem such that a solidified region 8-8 (hatched portion shown in Fig. 8(B)) is formed outside the contour 8-1 of the desired model shape. A contour plane of an actual shape to be modeled becomes an enveloping plane 8-9 of the hatched portion, and this plane 8-9 does not accord with the contour plane 8-1 of the desired model shape.

The above-mentioned problem such that the plane 8-9 is formed outside the contour 8-1 as shown in Fig. 8(B) is not limited in the case of exposure of a light beam. For example, referring to Fig. 9(E), 9-1 denotes a contour of a desired model shape in vertical section, and 9-6a, 9-6b, 9-6c and 9-6d denote solidified regions by exposure of light through a mask film. As apparent from Fig. 9(E), the solidified regions are formed beyond the contour 9-1 in the case that the desired model shape is downwardly narrowed. Thus, a satisfactory solidified image of the desired model shape cannot be obtained also in the case of using the mask film.

It is accordingly an object of the present invention to provide an improved photo-solidification modeling device.

According to one aspect of the present invention, there is provided a photo-solidification modeling device for forming a solidified three-dimensional object having a shape corresponding to a desired three-dimensional model shape including an inwardly-sloping outer model contour by exposing to light selected regions of a liquid capable of being solidified by exposure to the light to form the desired three-dimensional object, the device comprising:

means for representing the desired three-dimensional model shape by a plurality of sets of coordinates each defining a point on a contour in a section of the desired three-dimensional model shape; and

means for computing a corresponding plurality of sets of offset exposure coordinates defining regions of the liquid to be exposed to light to form the three-dimensional object with an inwardly-sloping outer contour corresponding to the inwardly-sloping outer model contour of the three-dimensional model.

According to a second aspect of the present invention there is provided a photo-solidification modelling device for solidifying liquid so as to create a solidified image having a desired three-dimensional shape, comprising:

a container for storing the liquid;

a light source for generating light for solidifying the liquid;

light transmitting means for guiding said light generated by said light source to regions of the liquid;

a controller for defining a region where said light is to be transmitted;

means for computing a solidified shape of the liquid at a boundary between the light transmitted region and non-transmitted region; and

second computing means for calculating an offset quantity for the outermost light transmitted region so as to make a three-dimensional solidified shape at said boundary contact with the desired three-dimensional shape.

According to a third aspect of the present invention there is provided a photo-solidification modeling device comprising:

a container for storing a liquid capable of being solidified upon exposure to light;

a light source for generating light for solidifying the liquid;

light transmitting means for guiding said light generated by said light source to regions of the liquid;

a controller for defining an outermost region of said light transmitted by said light transmitting means;

means for calculating a shape to be solidified in the liquid at a boundary of said outermost region;

computing means for calculating an offset quantity so as to make a three-dimensional solidified shape at said outermost region contact with a desired model shape.

The invention also provides a photo solidification method for solidifying liquid so as to create a solidified image having a desired three-dimensional shape, comprising the steps of:

generating light for solidifying the liquid;

guiding the light to regions of the liquid;

defining a region of the liquid to which the light is to be transmitted;

computing a solidified shape of the liquid at a boundary between a light transmitted region and a non-transmitted region;

calculating an offset quantity for the outermost light transmitted region; and

exposing the liquid to the light in accordance with the offset quantity to make a three-dimensional solidified shape at the boundary contact with the desired three-dimensional shape.

Another aspect of the invention provides a photo solidification modelling method or forming a solidified three-dimensional object having a shape corresponding to a desired three-dimensional model shape including an inwardly-sloping outer model contour by exposing to light selected regions of a liquid capable of being solidified by exposure to the light to form the desired three-dimensional object comprising the steps of:

representing the desired three-dimensional model shape by a plurality of sets of light beam coordinates; and

computing a corresponding plurality of sets of light beam offset exposure coordinates defining regions of the liquid to be exposed to light to form the three-dimensional object with an inwardly-sloping outer contour corresponding to the inwardly-sloping outer model contour of the three-dimensional model.

With the invention a photo-solidification modelling device may be produced which can offset the contour of the exposure region inside so that the three-dimensional contour plane of the solidified region caused by exposure to light will be in accord with the three-dimensional contour plane of the desired model shape.

The invention will further be understood from the following description, when taken together with the attached drawings, which are given by way of example only, and in which:

Figs. 1(A) to 1(C) are block diagrams of a preferred embodiment of the present invention;

Figs. 2(A) and 2(B) are flowcharts of the essential operation of the system;

Fig. 3 is a schematic perspective view illustrating a triangular patch type of three-dimensional shape data;

Fig. 4 is an illustration of a data structure of the triangular patch type;

Fig. 5(A) is a perspective view of an example of an extracted horizontal plane;

Fig. 5(B) is a schematic illustration of extraction of a horizontal plane;

Fig. 6 is a schematic illustration of extraction f a

contour;

Fig. 7 is a plan view of the contour extracted;

Fig. 8(A) is a plan view illustrating a conventional offsetting method;

Fig. 8(B) is a three-dimensional view of Fig. 8(A);

Fig. 8(C) is a perspective view of a solidified region formed by light beam exposure;

Fig. 9(A) is a three-dimensional view illustrating an offset quantity calculating method;

Fig. 9(B) is a vertical sectional view of Fig. 9(A);

Figs. 9(C) and 9(D) are vertical sectional views of a solidified region formed in consideration of an offset quantity in the case of using a light beam according to the prior art and the present invention, respectively;

Figs. 9(E) and 9(F) are views similar to Figs. 9(C) and 9(D), in the case of using a mask film;

Fig. 10(A) is a perspective view of a contour of a desired model shape;

Figs. 10(B) to 10(F) are horizontal sectional views illustrating various exposure modes for exposing an inside region surrounded by the contour shown in Fig. 10(A);

Fig. 10(G) is a plan view illustrating an offsetting method for the exposure region to be formed inside the contour;

Fig. 10(H) is a cross section taken along the line H - H in Fig. 10(G);

Fig. 11(A) is a perspective view of support legs of a model;

Figs. 11(B) to 11(E) are plan views of various patterns of support legs;

Fig. 12(A) is a perspective view of a frame;

Fig. 12(B) is a perspective view of a supporting structure formed by the frame and support;

Figs. 13(A) to 13(C) are vertical sectional views illustrating various modes for setting a support forming region;

Fig. 14(A) is a perspective view illustrating a problem in the case of forming a hollow model having a gentle slant surface;

Fig. 14(B) is a horizontal sectional view of Fig. 14(A);

Fig. 15(A) is a perspective view of a coating brush mechanism; and

Fig. 15(B) is an enlarged side view of the brush of Fig. 15(A).

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

According to the present invention, a high-precision photo-solidification modeling device is provided for forming a solidified image having a desired model shape by exposing regions corresponding to the desired model shape to light a liquid capable of being solidified by such exposure. The device includes means for computing a quantity for offsetting a contour of the exposure region toward the inside of a three-dimensional contour plane of the desired model shape so as to make a three-dimensional contour plane of the solidified image coincident with the three-diuensional contour plane of the desired model shape.

The provision of the offset quantity computing means prevents the contour of the solidified region in each section from being formed outside the contour of the desired model shape, and ensures that it is made substantially in accordance with the contour of the desired model shape as shown in Figs. 9(D) and 9(F). Thus, the problem of the hatched portion 8-8 in Fig. 8(B) can be elimnated. Such an offset operation is effective not only in the case of exposure of a light beau in every section, but also in the case of exposure to light of an entire liquid surface as in Fig. 9(F), or in the case of exposure by a light beam movable in three-dimensions in a liquid.

As described above, the contour of the exposure region is offset inside so that the three-dimensional contour plane of the solidified region by the exposure of light may be made in accordance with the three-dimensional contour plane of the desired model shape. Accordingly, the solidified image is prevented from being formed outside the contour of the desired model shape, and a solidified model of a desired shape may be accurately obtained. It is further advantageous in that the modeling accuracy in the photo-solidification modeling device can be improved, and the advantages of the photo-solidification modeling method can be obtained in various applications.

A preferred embodiment of the present invention will now be described in detail. Figs. 1(A) to 1(C) show an example of a system construction of the photo-solidification modeling device according to the present invention. Figs. 2(A) and 2(B) are flowcharts showing operations of the system shown in Figs. 1(A) to 1(C).

Referring to Fig. 1(C), 1-46 denotes a closed container for storing a liquid that is solidified when exposed to light. The container 1-46 has a transparent upper surface, and the liquid is preferably a photosensitive resin. More preferably, the liquid may be a mixture of one, two, or more of deformed polyurethane methacrylate, oligoester acrylate, urethane acrylate, epoxy acrylate, photosensitive polymide, and aminoalkyd.

Further, a sensitizer or opaque substance, etc., may be mixed in the liquid to adjust its photoabsorption characteristic or the like. Further, a pigment, ceramic powder, filler, metal powder, etc., may be mixed in the liquid to adjust the color, strength, distortion, modeling accuracy, etc., of a model.

A base 1-45 is vertically (Z direction) movable in the container 1-46 below a liquid surface 1-43. A light source (preferably, a laser) 1-38 is provided above the container 1-46. Light from the light source 1-38 is introduced to an optical fiber 1-40 through a filter 1-39 having both a light shutter function and an exposure

quantity adjusting function. A tip 1-40a of the optical fiber 1-40 is movable by an XY driving mechanism 1-41 in two orthogonal directions (XY directions). A brush 1-42 capable of sweeping the liquid surface 1-43 is movable in the Y direction shown.

A solidification modeling part of the present device is formed by the above construction, and it is controlled in the following manner by a system to be hereinafter described.

First, the base 1-45 is lowered below the liquid surface 1-43 by a unit thickness ΔZ of a model. Under this condition, the tip 1-40a of the optical fiber 1-40 is scanned in the XY directions in a region corresponding to a lowermost section of a desired model shape. As a result, the liquid in the region exposed to light is solidified to form a section solidified image 1-44a corresponding to the lowermost section of the desired model shape on the base 1-45.

Then, the base 1-45 is further lowered by ΔZ. As a result, the lowermost section solidified image 1-44a is also lowered together with the base 1-45, and simultaneously the peripheral liquid is coated over the lowermost section solidified image 1-44a.

As the liquid has a high viscosity, it does not easily flow onto the solidified image 1-44a if the base 1-45 is merely lowered by ΔZ. To avoid this disadvantage, the brush 1-42 is operated to sweep the liquid surface 1-43, to positively coat the liquid onto the solidified image 1-44a. Then, the tip 1-40a of the optical fiber 1-40 is selectively scanned in the XY directions to form a subsequent section solidified image 1-44b on the solidified image 1-44a. The above operation is repeated until a laminated solidified image having the desired model shape is formed in the liquid. More detailed explanation will be omitted since the above concept is basically disclosed in Japanese Laid-Open Patent Publication No. 56-144478.

Reference number 1-28 in Fig. 1(C) denotes an external system connected to the present system by way of on-line or off-line connection. Such an external system may be selected from a three-dimensional CAD system, three-dimensional measuring instrument, continuous tomographic system, etc. These are merely exemplary, and it is sufficient for the external system to have data relating to a three-dimensional shape of the model.

If the form of data included in the external system 1-28 is of a triangular patch type, the data is directly stored into a triangular patch type desired model shape data storing means 1-7 in the present system.

If the form of data included in the external system 1-28 is of a type other than the triangular patch type, the data is converted into the triangular patch type by a triangular patch type converting means 1-31 in the present system, and is then stored into the storing means 1-7.

A schematic construction of the triangular patch type data is shown in Figs. 3 and 4. As apparent from Fig. 3, the three-dimensional shape is defined as a set of many triangular patches P_I, P_J, P_K, etc., in the triangular patch type. In Fig. 3, only part of the set of these triangular patches is shown for the purpose of legibility of illustration.

Each triangular patch is defined in position and shape by XYZ coordinates of three vertexes. For instance, the patch P_J is given XYZ coordinates of three vertexes J_1, J_2 and J_3. Accordingly, the three-dimensional shape data of the triangular patch type has a structure as shown in Fig. 4.

The data having the structure shown in Fig. 4 and stored into the storing means 1-7 may be edited by a data editing means 1-8 shown in Fig. 1(B) (see step 2-8 in Fig. 2(A)). In this editing operation, the desired mode shape data can be expanded, contracted, rotated or corrected. Especially, in the correcting operation, data for defining the shape of a structure for supporting the desired model shape may be added. Further, new three-dimensional shape data may be created by using this correcting function.

When an operator of this system sets a unit thickness and a beam diameter by using a unit thickness setting means 1-1 and a beam diameter setting means 1-2 shown in Fig. 1(A) (see step 2-1 in Fig. 2(A)), a perspective view of the edited desired model shape sliced with the unit thickness is displayed on a two-dimensional display 1-32 (see step 2-50 of simulation and step 2-32 of displaying in Fig. 2(A)). Then, the operator confirms whether or not the modeling is to be started under the above condition, and if NO in step 2-51, the operator resets the condition (see the loop from step 2-51). If the condition is satisfied, the following processing is executed in the present system.

First, a beam scanning speed computing means 1-9 shown in Fig. 1(B) computes an optimum scanning speed for solidifying the unit thickness set by the means 1-1 with the beam diameter set by the means 1-2. Then, a horizontal plane extracting means 1-10 is started in step 2-10 to extract a horizontal plane from the desired model shape.

In this preferred embodiment, the unit thickness ΔZ set by the means 1-1 is employed, and as shown in Fig. 5(B), triangular patches each having the three vertexes all contained within the height range of ΔZ are searched to compute an outside contour 5-1 of the set of triangular patches.

Fig. 5(B) shows a virtual side view of these triangular patches, in which the three vertexes of each patch P_I reside inside the width of the unit thickness ΔZ, and at least one of the three vertexes of each patch P_O resides outside the width of the unit thickness ΔZ. Thus, the contour 5-1 of the horizontal plane is extracted and computed from the outermost line of the set of the patches P_I.

The inside area surrounded by the contour 5-1 in the horizontal plane extracted above is uniformly exp-

osed to light to be solidified. Fig. 5(A) is a virtual view of horizontal planes 5-1a and 5-1b extracted from the triangular patch data shown in Fig. 3.

Then, the present system executes computation of a contour by using a contour computing means 1-11 shown in Fig. 1(B) (see step 2-11 in Fig. 2(A)).

Fig. 6 is a schematic illustration of contour computing in which each non-horizontal triangular patch (patches S and T being exemplarily shown in Fig. 6) intersects a horizontal plane Z sliced with the unit thickness ΔZ, and two intersections between each patch and the plane Z are computed.

As shown in Fig. 6, the two intersections between the patch S and the plane Z are denoted by $(X_L, Y_L)S$ and $(X_R, Y_R)S$, while the two intersections between the patch T and the plane Z are denoted by $(X_L, Y_L)T$ and $(X_R, Y_R)T$. As the patches S and T are adjacent to each other, a common intersection resides on the adjacent line. That is, the intersection $(X_R, Y_R)S$ is coincident to the intersection $(X_L, Y_L)T$.

Then, on the basis of these intersection coordinates computed above, plural contours 7-1, 7-2, 7-3, etc., in a certain section as shown in Fig. 7 are computed.

As shown in Fig. 3, there is a case that the triangular patches in some section are not continuous to define a gap G. That is, the extracted contours 7-1 and 7-2 do not form a closed curve. In this case, the nearest intersections are searched, and they are connected together to obtain a closed curve. As shown in Fig. 7, the contours thus computed are classified into a group for forming a desired model shape inside the contour (e.g., 7-1) and a group for forming the desired model shape outside the contour (e.g., 7-2). Such classification is effected by searching the contours along a search line 7-4 from the left side, for example, and giving an inside indicating flag for the contour 7-1 first intersecting the search line 7-4 and an outside indicating flag for the contour 7-2 secondly intersecting the search line 7-4.

Referring back to Fig. 1(B), the present system includes a beam corresponding solidifying region data computing and storing means 1-12 for computing and storing a sectional shape of a region to be solidified when the beam having the beam diameter set by the means 1-2 is scanned at the speed computed by the means 1-9. That is, as shown in Fig. 8(C), the means 1-12 computes and stores a sectional shape F2 of a region F1 to be solidified when a light beam 8-12 is scanned as shown by an arrow 8-10. Then, a three-dimensional offset quantity computing means 1-13 shown in Fig. 1(B) computes a three-dimensional offset quantity for the horizontal line data extracted by the means 1-10 and the contour data computed by the means 1-11 by using solidifying region data computed by the means 1-12.

The computation of such a three-dimensional offset quantity will now be described with reference to Figs. 8(A) to 8(C) and Figs. 9(A) to 9(F).

Referring to Fig. 8(A) which is a plan view of the liquid surface, 8-2 denotes an exposure region of the light beam. In the case that the center 8-3 of the exposure region 8-2 is scanned along a contour 8-1 (computed by the means 1-11) as shown by an arrow 8-4, a contour 8-5 of a region to be solidified is undesirably formed outside the contour 8-1.

Fig. 8(B) is a stereoscopic view of Fig. 8(A). As shown in Fig. 8(B), in the case that the center of the light beam resides on the contour of the model, regions 8-5a, 8-5b, 8-5c, etc., are solidified, and the contour of an actual solidified region to be formed by continuously connecting outermost surfaces of the regions 8-5a, 8-5b, 8-5c, etc., does not coincide with the contour 8-1.

To avoid the above problem, the conventional photo-solidification modeling device practically used at present is designed to scan the center of the light beau along a line offset inside of the contour by a distance equal to the radius of the beam as shown in a left lower area of Fig. 8(A).

As shown in the left lower area of Fig. 8(A), in the case that the center 8-6 of the light beam is offset inside of the exposure region 8-2 by a radius d of the light beam, the contour of the solidified region becomes coincident with the contour 8-1 as far as viewed in plan.

However, it is understood from Fig. 8(B) that a problem remains from a stereoscopic standpoint. As shown in Fig. 8(B), 8-8 denotes a region to be solidified by a light beam that has been offset inside by the radius d. Since the desired model shape is gradually narrowed in the direction of the lowermost surface, it is understood that an excess region 8-8 (the hatched portion) is solidified. Accordingly, a contour 8-9 of an actual model shape is formed outside the contour 8-1 of the desired model shape.

Figs. 9(A) to 9(F) show a method of three-dimensionally offsetting the exposure region of the light beam, so as to eliminate the above problem.

Fig. 9(A) shows a three-dimensional coordinate system wherein the origin coincides with one of the intersections between the triangular patch and the horizontal plane Z shown in Fig. 6. In this preferred embodiment, the origin of the coordinate system shown in Fig. 9(A) coincides with the intersection $(X_R, Y_R)S$ or $(X_L, Y_L)T$.

Referring to fig. 9(A), F2A to F2d denote a common three-dimensional shape to be formed by rotating the sectional shape F2 shown in Fig. 8(C) about the center of the beam, and $\overline{N}$ denotes a unit normal vector at the origin, i.e., the intersection $(X_R, Y_R)S$ or $(X_L, Y_L)T$. The unit normal vector $\overline{N}$ is calculated as a vector sum of unit normal vectors $\overline{N}_S$ and $\overline{N}_T$ with respect to the adjacent patches shown in Fig. 6. Direction of each of the unit normal vectors $\overline{N}_S$ and $\overline{N}_T$ is computed from the vertex coordinates of each patch,

and the sense of each vector is defined with reference to the inside and outside indicating flags previously mentioned in relation to the search line 7-4 in Fig. 7. In this preferred embodiment, the sense of each vector is defined such that each vector is oriented from the inside to the outside of the desired model shape. The unit normal vector $\overline{N}$ thus computed has components nx, ny and nz.

In Fig. 9(A), $\overline{n}_R$ denotes a vector having the components n_x and n_y in the XY plane, and an R axis is given in the direction of the vector $\overline{n}_R$. Fig. 9(B) shows an RZ plane given in Fig. 9(A).

As shown in Figs. 9(A) and 9(B), F2A denotes a solidified region to be obtained when the beam center coincides with the intersection (i.e., the origin in this case). It is apparent that a large proportion of the solidified region F2A is undesirably formed outside the contour 8-1. F2B denotes a solidified region to be obtained when the beam center is offset inside the contour 8-1 along the R axis by the radius d. It is understood that a hatched portion of the solidified region F2B is also undesirably formed outside the contour 8-1. In contrast, F2C denotes a solidified region to be obtained when the beam center C1 is offset inside the contour 8-1 so that a three-dimensional contour 9-2C of the solidified region F2C passes the intersection (the origin) and that a normal vector for the contour 9-2C coincides with the normal vector $\overline{N}$ for the contour 8-1 at the origin. In other words, the solidified region F2C is offset inside the contour 8-1 so that the contour 9-2C of the solidified region F2C intersects the contour 8-1 at the origin.

In this case, assuming that the solidified region F2C is a spheroid having a minor axis "d" and a major axis "h," the above relation can be satisfied by offsetting the beam center by a distance R_1 along the R axis and a distance Z_1 along the Z axis, wherein R_1 and Z_1 are defined as follows:

$$R_1 = d^2 n_R/(h^2 n_z 2 + d^2 n_R 2)^{\frac{1}{2}}$$

$$Z_1 = h^2 n_z/(h^2 n_z 2 + d^2 n_R 2)^{\frac{1}{2}}$$

where $n_R = (n_x^2 + n_y^2)^{\frac{1}{2}}$

On the other hand, F2D denotes a solidified region to be obtained by moving the solidified region F2C in a direction perpendicular to the normal vector $\overline{N}$ in the RZ plane so that a Z coordinate of the beam center CO becomes zero.

As apparent from Fig. 9(B), the portion of the solidified region F2D outside the contour 8-1 becomes substantially zero.

The solidified region F2D can be obtained by offsetting the beam center by a distance X_0 along the X axis and a distance Y_0 along the Y axis, wherein X_0 and Y_0 are defined as follows:

$$X_0 = n_x(d^2 n_x^2 + d^2 n_y^2 + h^2 n_z^2)^{\frac{1}{2}}/(n_x^2 + n_y^2)$$

$$Y_0 = n_y(d^2 n_x^2 + d^2 n_y^2 + h^2 n_z^2)^{\frac{1}{2}}/(n_x^2 + n_y^2)$$

In this case, the contour of the three-dimensional solidified region can be made substantially coincident with the contour of the desired model shape without changing the height of the beam center.

By using either the former method or the latter method, the means 1-13 computes an offset quantity of the beam center.

In the case of controlling the exposure region in every horizontal section as in this preferred embodiment, the latter method is suitably adopted. In the case of controlling the exposure region by immersing the tip of the optical fiber into the liquid and moving the tip in the XYZ directions, the former method may be adopted to three-dimensionally offset the beam center.

Fig. 9(C) shows a vertical section of a laminated solidified region in the case of offsetting the beam center by the radius d. In contrast, Fig. 9(D) shows a vertical section of a laminated solidified region in the case of offsetting the beam center by the distances X_0 and Y_0 as mentioned above. As apparent from Figs. 9(C) and 9(D), a contour 9-12 of the laminated solidified region according to the offsetting method of the present invention as shown in Fig. 9(D) is made substantially coincident with a contour 9-1 of the desired model shape having a downwardly tapering shape.

The above-mentioned problem occurs not only in the case of using a light beam but also in the case of using a mask film or a projector to expose the liquid surface to light uniformly as shown in Fig. 9(E).

Fig. 9(E) shows the case where a contour of each exposure region is made coincident with the downwardly tapering contour 9-1 of the desired model shape. As apparent from Fig. 9(E), hatched portions 9-6a, 9-6b, 9-6c, 9-6d, etc., of the exposure regions are excessively solidified outside of the contour 9-1.

In contrast, Fig. 9(F) shows an improvement with respect to Fig. 9(E), wherein contours 9-11a, 9-11b, 9-11c, 9-11d, etc., of the solidified regions are offset inside by the amount of R_0 so as to contact the downwardly tapering contour 9-1. According to this method, the contour 9-12 of the solidified image can be made substantially coincident with the contour 9-1 of the desired model shape.

After the means 1-13 couputes the optimum offset quantity as mentioned above, a contour corresponding exposure region data computing and storing means 1-14 computes and stores data relating to a scanning position of the beam center for offsetting the exposure region by the computed offset quantity and solidifying the exposure region corresponding to the horizontal line extracted by the means 1-10 or the contour computed by the means 1-11.

In this preferred embodiment, the present system further includes a means 1-3 for setting an exposure mode for an inside region 7-5 surrounded by the contours 7-1 and 7-2 or an inside region 7-6 surrounded by the contour 7-3 as shown in Fig. 7, for instance (see step 2-3 in Fig. 2(A)).

This exposure mode is classified into a non-exposure mode, whole region exposure mode, and

spaced exposure mode.

In the first case of setting the non-exposure mode by using a means 1-3a, a hollow model solidified at the contour only is fabricated as shown in Fig. 10(F). In this mode, an outer surface 10-2a shown in Fig. 10(F) corresponding to a contour 10-2 shown in Fig. 10(A) is solidified, and an inner surface 10-3a shown in Fig. 10(F) corresponding to a contour 10-3 shown in Fig. 10(A) is also solidified. However, an inside region between the contours 10-2 and 10-3 is not solidified to define a hollow portion 10-8, thus fabricating a hollow model.

This mode is effective in the case where the model shape only is important, and high strength is not required. As the exposure region is small, the modeling time can be shortened.

In the second case of setting the whole region exposure mode by using a means 1-3b, the inside region between the contours 10-2 and 10-3 is wholly solidified to fabricate a solid model as shown in Fig. 10(B). This mode is suitable in the case where the model must have high strength.

In the third case of setting the spaced exposure mode by using a means 1-3c, the operator can select one of a normal cross mode (Fig. 10(C)), alternate cross mode (Figs. 10(D)1 and 10(D)2), and stripe mode (Fig. 10(E)).

In the stripe mode shown in Fig. 10(E), the inside region is spacedly exposed in one direction. In the normal cross mode shown in Fig. 10(C), the inside region is spacedly exposed in two different directions in the same section. In the alternate cross mode, shown in Figs. 10(D)1 and 10(D)2, the inside region is spacedly exposed by alternating the scanning direction in the stripe mode in every section.

The spaced exposure mode can set by using a means 1-3c, to select a desired pattern (i.e., normal cross, alternate cross, or stripe), having a selected pitch and exposure width. The exposure width can be set to be different from the beam diameter set by the means 1-2.

According to the spaced exposure mode, a honeycomb structure is additionally formed in the hollow model to fabricate a honeycomb model.

After setting the exposure mode for the inside region, an offset means 1-17 is started. The offset means 1-17 computes an offset quantity shown in Figs. 10(G) and 10(H). Referring to Fig 10(G), 10-14 denotes a light beam for exposing the contour. The light beam 10-14 is scanned in the direction of arrow 10-16 with the beam center being offset inside the contour to a position 10-15. On the other hand, 10-10 denotes a light beau for exposing the inside region. In the case that the scanning of the light beam 10-10 is stopped at a position where a leading end 10-11a of the light beam 10-10 contacts the circumference of the light beam 10-14, a contour corresponding solidified region 10-14a is not sufficiently connected to an inside region corresponding to solidified region 10-10a as shown in Fig. 10(H)(1), with result that a sufficient supporting effect by the honeycomb structure cannot be obtained.

In contrast, when the scanning of the light beam 10-10 is stopped at a position where the beam center 10-13 of the light beam 10-10 coincides with the beam center 10-15 of the light beam 10-14, an extra solidified region 10-18 is formed by the beam 10-10 outside the circumference of the contour corresponding solidified region 10-14a as shown in Fig. 10(H)(3), with the result that the desired model shape cannot be precisely obtained.

In consideration of these problems, the offset means 1-17 computes an optimum offset quantity of the light beam 10-10 in such a manner that the scanning of the light beam 10-10 is stopped at a position where the leading end 10-12a of the light beam 10-10 contacts the beam center 10-15 of the light beam 10-14, that is, the beam center 10-12 of the light beam 10-10 is offset inside the circumference of the light beam 10-14 by a radius of the light beam 10-10 (see Fig. 10(H)(2)). The exposure region in the inside region is computed and stored by an inside region corresponding exposure region data computing and storing means 1-18 according to the information set by the means 1-3 and the offset quantity computed by the means 1-17 (see step 2-18 in Fig. 2(A)).

Such an overlapping range between the contour corresponding exposure region and the inside region corresponding exposure region may be appropriately set by the operator within the range between Figs. 10(H)(1) and Fig. 10(H)(3).

Further, the operator can set leg data by using a means 1-4 included in the present system. Referring to Fig. 11(A), a plurality of legs 11-9 are formed on the base 1-45 in the container 1-46. A desired model shape 11-1 is formed on the legs 11-9. If the solidified image of the model is directly laminated on the base 1-45 without the legs 11-9, the solidified image will be broken or distorted when removed from the base 1-45. The legs 11-9 prevent this problem.

As shown in Fig. 11 (A), the legs 11-9 are formed in spatial ranges 11-4a and 11-4b corresponding to lowermost sections 11-3a and 11-3b searched by using a means 1-19. The legs 11-9 are also formed in a frame setting space 11-2 to be hereinafter described.

The leg data defines leg height, pitch, line width and pattern (stripe, normal cross, or alternate cross). These data are set by using means 1-4a and 1-4b. The leg data further defines if an outline is present or absent. This data is set by using a means 1-4c.

Leg height is th height of each leg to be solidified prior to modeling of the desired model shape. The pattern, pitch and lin width are the same as those previously mentioned. The outlin means an outline to be formed along a boundary of a leg forming region.

In the case that the presence of the outline is set by the means 1-4c, a peripheral leg 11-7 (see Fig. 11(D)) or a peripheral leg 11-8 (see Fig. 11(E)) is formed along the boundary of the leg forming region 11-4a.

In the case where the outline is not set by the means 1-4c, no peripheral leg is formed as shown in Figs. 11(B) and 11(C).

Figs. 11(B) and 11(D) show the case where the stripe mode is selected to form stripe legs 11-5. Figs. 11(C) and 11(E) show the case where the normal cross mode is selected to form normal cross legs 11-6.

After the leg data is entered by the means 1-4 (see step 2-4 in Fig. 2(B)), a leg corresponding exposure region data computing and storing means 1-20 computes and stores exposure region data for the formation of the legs by referring to the leg data as entered above, the information of the lowermost section, and data relating to a frame setting space which will be hereinafter described (see step 2-20 in Fig. 2(B)).

The operator can set the frame setting space by using a means 1-5 in the present system. In this case, the operator can select whether a whole space is to be set by using a means 1-5a or a specific space is to be set by using a means 1-5b.

In the case of setting the whole space, a maximum contour range computing means 1-21 is started to compute a rectangular parallelepiped 12-2 entirely covering a desired model shape 12-1 as shown in Fig. 12(A). Then, a frame corresponding exposure region data computing and storing means 1-22 computes and stores exposure region data for forming a frame to be solidified at four side walls of the rectangular parallelepiped 12-2.

In the case of setting the specific space, such a specific space is specified by coordinate data (X_1, Y_1) and (X_2, Y_2) of a diagonal as shown in Fig. 12(A), and the means 1-22 computes and stores exposure region data for forming a frame to be solidified at four side walls of a rectangular parallelepiped 12-3 having a rectangular bottom surface defined by the above diagonal.

The frame functions as a model shape supporting means in cooperation with a support to be formed inside the frame as will be hereinafter described.

The support data is set by specifying a pitch, line width, and pattern (stripe, normal cross, or alternate cross) of a support to be formed in the frame space for every given height by using a means 1-6a. After setting the support data, an exposure region data is computed to form the support in the frame space according to the support data set above.

More specifically, pattern data is previously stored in a regular regions (patterns) data computing and storing means 1-23, and one of the pattern data, that is, one of the stripe, normal cross, and alternate cross is output from the means 1-23. Th n, a support corresponding exposure region data computing and storing means 1-26 computes and stores exposure region data for forming the support by using the above specified pattern data as well as the pitch and line width data.

Fig. 12(B) shows a complex of frames 12-4a, 12-4b, and 12-4c and supports 12-4b1 and 12-4c1 formed inside the frames 12-4b and 12-4c, respectively, in the frame space 12-3 as the rectangular parallelepiped shown in Fig. 12(A). The complex consists of a first element formed by the frame 12-4a only in a height range 0-H_1, a second element formed by the frame 12-4b and the stripe supports 12-4b1 in a height range H_1 - H_2, and a third element formed by the frame 12-4c and the normal cross supports 12-4c1 in a height range H_2 - H_3.

In setting the support data under the condition where the whole frame space is set, the operator can select one of a lower whole region, outside whole region, and inside and outside whole region by using a region setting means 1-6b.

More specifically, when the lower whole region is set by a means 1-6b1, the support is formed in a lower region 12A of the frame space 12-2 below the desired model shape as shown in Fig. 13(A) (vertical section). In this case, a lower surface 12-5 of the desired model shape is searched by a lowermost contour surface searching means 1-24.

When the outside hole region is set by a means 1-6b2, the support is formed in a whole region 12B of the frame space 12-2 outside the desired model shape as shown in Fig. 13(B). In this case, upper surfaces 12-3 and lower surfaces 12-4 of the desired model shape are searched by an upper and lower contour surfaces searching means 1-25.

When the inside and outside whole region is set by a means 1-6b3, the support is formed in the whole of the frame space 12-2 as shown in Fig 13(C).

Further, the present system also includes a means 1-15 for determining the continuity of a contour corresponding solidifying region.

As shown in Fig. 14(A), for instance, the means 1-15 determines whether contour corresponding solidifying regions 14-1 and 14-2 in vertically adjacent sections Z_0 and Z_1 are continuous with each other. In the case that the sections Z_1 and Z_0 are largely different in size as shown in Figs. 14(A) and 14(B), the solidifying region 14-1 becomes discontinuous from the solidifying region 14-2. Accordingly, in the case of forming a hollow model, the solidifying region 14-1 would be in a floating state. To avoid this problem, the hollow model setting mode is forcibly converted into the solid model setting mode by a means 1-16 to expose the whole region inside of the section Z_0 in this case to the light beam. As a result, ven when the d s-ired model shape has a gentl slant surface, a hollow model having a continuous peripheral surface can be

fabricated.

As described above, the exposure region data corresponding to the contour, inside region, leg, frame and support are computed and stored in the respective computing and storing means 1-14, 1-18, 1-20, 1-22 and 1-26. Thereafter, the modeling is actually started. First, the leg is formed by the exposure according to the exposure region data corresponding to the leg. After the height of the leg reaches a predetermined value, the frame, support, and inside region in the lowermost section are formed by exposure according to the exposure region data corresponding to the frame, support, and inside region. Finally, the contour is formed by exposure according to the exposure region data corresponding to the contour.

By finally forming the contour as mentioned above, a local change in liquid level due to the fact that the liquid is surrounded by a solidified image can be suppressed to minimize distortion of the model shape during modeling. In the actual control of the exposure, the filter 1-39 is controlled by an exposure intensity control means 1-33, and the XY driving mechanism 1-41 for moving the tip 1-40a of the optical fiber 1-40 in the XY directions is controlled by a horizontal exposure position control means 1-34. Further, a scanning speed is controlled by a scanning speed control means 1-35. The filter 1-39 and the scanning speed are controlled in coordination with each other.

Further, the lowering of the base 1-45 by the unit thickness ΔZ after the exposure for one section is carried out by height control means 1-37.

After lowering the base 1-45 by the unit thickness ΔZ, the brush 1-42 is moved in a direction (Y direction) perpendicular to a longitudinal direction (X direction) of the brush 1-42 by a brush sweeping control means 1-36.

Referring to Fig. 15(A), the brush may be comprised of a first brush 15A and a second brush 15B arranged in parallel to each other at a given interval and adapted to be moved together. The first brush 15A is provided with a plurality of brush elements $15A_1$, $15A_2$, $15A_3$, etc., spaced at regular intervals in the longitudinal direction of the first brush 15A. Similarly, the second brush 15B is provided with a plurality of brush elements $15B_1$, $15B_2$, $15B_3$, etc., spaced at regular intervals in the longitudinal direction of the second brush 15B in such a manner that the brush element $15B_1$ is located at a position opposed to a space between brush elements $15A_1$ and $15A_2$ of the first brush 15A, and the other brush elements of the second brush 15B are also located in the same manner as above. With use of such a brush, the liquid can be coated with a uniform thickness even on a large solidified layer of the model shape as in the case of fabricating a solid model.

As to th arrangement of the brush elements, the best result of coating of the liquid was obtain d by setting a width L2 of each brush element to 2 mm and setting a spacing L1 between the adjacent brush elements to 1 mm. As shown in Fig. 15(B), the liquid is carried as the form of a wave 15D onto a solidified image 15E by the brush. Accordingly, if the spacing L1 is too wide, good wave formation cannot be obtained. Conversely, if the spacing L1 is too narrow, the volume of the wave 15D becomes large, and accordingly a coating layer 15C of the liquid cannot be desirably formed. Further, if the length of each brush element is too small, the wave 15D cannot be sufficiently formed, and an amount of the liquid to be retained among fibers of the brush element is not sufficient, resulting in defective coating. On the other hand, if the length of each brush element is too large, the size of the wave 15D becomes large resulting in defective coating.

Further, the material, thickness, and sweeping speed of the brush element are also important. If the brush element is too hard, the solidified image is broken by the brush element. If the brush element is too soft, or the sweeping speed is too slow, the wave effect cannot be obtained. These factors should be suitably selected in consideration of the properties of the liquid and the solidified image. In any case, it is beneficial if the brush elements be spaced at regular intervals in the longitudinal direction of the brush so as to obtain a good coating.

Further, since the first brush 15A and the second brush 15B are arranged in parallel as shown in Fig. 15(A), the thickness of the coating layer 15C can be made uniform even in the case of sweeping a wide surface of the solidified image 15E.

According to the above preferred embodiment, the contour corresponding exposure region data is decided in consideration of a three-dimensional offset quantity with respect to a contour of a desired model shape. The three-dimensional offset quantity is a quantity for offsetting a contour of a solidified region to make the same contact the contour of the desired model shape. Therefore, the contour of the solidified region can be made precisely coincident with the contour of the desired model shape by the exposure according to the data decided in consideration of the offset quantity. Thus, the accuracy of the desired model shape can be greatly improved.

Furthermore, according to the preferred embodiment, it is possible to select a solid, hollow or honeycomb model according to the intended use of the model. Accordingly, the intended use itself can be widened (for instance, the hollow model can be applied to a casting die), and modeling time can be shortened according to the intended use of the model to widen the intended use of the system.

Furthermore, as the supporting structure (support and frame) is formed in the modeling of the desired model shape, the accuracy of the desired model shape can be highly retained. In connection with this, the diameter of the beam for forming this supporting

structure can be set independently of that for forming the desired model shape. Accordingly, the supporting structure can be easily removed after the modeling is terminated.

Further, as the kind and exposure region of the supporting structure can be specified, the supporting structure can be formed at a necessary part only to reduce the modeling time.

Further, as the frame can be set in relation to the support, the kind, pitch, etc., of the support can be modified in every height of the frame to reduce the modeling time.

In addition, the liquid is coated on the solidified image by using the brush having a plurality of brush elements spaced at regular intervals. Therefore, the liquid can be coated with a uniform thickness in a short time to improve modeling accuracy and reduce modeling time.

In conclusion, the system of the preferred embodiment includes various improvements in combination, and is superior to the conventional system.

While the invention has been described with reference to a specific embodiment, the description is illustrative and is not to be construed as limiting the scope of the invention. Various modifications and changes may occur to those skilled in the art without departing from the scope of the invention as defined by the appended claims.

Claims

1. A photo-solidification modeling device for forming a solidified three-dimensional object having a shape corresponding to a desired three-dimensional model shape including an inwardly-sloping outer model contour by exposing to light selected regions of a liquid capable of being solidified by exposure to the light to form the desired three-dimensional object, the device comprising:

   means for representing the desired three-dimensional model shape by a plurality of sets of coordinates each defining a point on a contour in a section of the desired three-dimensional model shape; and

   means for computing a corresponding plurality of sets of offset exposure coordinates defining regions of the liquid to be exposed to light to form the three-dimensional object with an inwardly-sloping outer contour corresponding to the inwardly-sloping outer model contour of the three-dimensional model.

2. A photo-solidification modeling device according to claim 1, further comprising:

   a light source for exposing the liquid to solidify the exposed regions of the liquid; and

   means for controlling said light source in accordance with said offset exposure coordinates.

3. A photo-solidification modeling device according to claim 2, wherein said light source is adapted to generate a light beam having a beam center, and wherein each of said sets of light beam offset exposure coordinates defines the offset of said beam center in two dimensions from corresponding coordinates defining the desired three-dimensional model shape.

4. A photo-solidification modeling device according to claim 3, wherein the shape of a region to be solidified corresponding to each of said light beam offset coordinates is a spheroid having a minor axis "d" and a major axis "h," and each of said offset exposure coordinates corresponds to offsetting the beam center by a distance R_1 along an R axis and a distance Z_1 along a Z axis, wherein R_1 and Z_1 are defined as follows:

   $$R_1 = d^2 n_R / (h^2 n_z^2 + d^2 n_R^2)^{1/2}$$
   $$Z_1 = h^2 n_z / (h^2 n_z^2 + d^2 n_R^2)^{1/2}$$

   where $n_R = (n_x^2 + n_y^2)^{1/2}$ and n_x, n_y, and n_z are components of a unit normal vector extending from the inside to the outside of the desired three-dimensional model shape.

5. A photo-solidification modeling device according to claim 3, wherein the shape of a region to be solidified corresponding to each of said light beam offset coordinates is a spheroid having a minor axis "d" and a major axis "h," and each of said offset exposure coordinates corresponds to offsetting the beam center by a distance X_0 along an X axis and a distance Y_0 along a Y axis, wherein X_0 and Y_0 are defined as follows:

   $$X_0 = n_x (d^2 n_x^2 + d^2 n_y^2 + h^2 n_z^2)^{1/2} / (n_x^2 + n_y^2)$$
   $$Y_0 = n_y (d^2 n_x^2 + d^2 n_y^2 + h^2 n_z^2)^{1/2} / (n_x^2 + n_y^2)$$

   and n_x, n_y, and n_z are components of a unit normal vector extending from the inside to the outside of the desired three-dimensional model shape.

6. A photo-solidification modeling device according to any preceding claim, wherein said computing means computes said light beam offset exposure coordinates to define the regions of the liquid to be solidified without changing the height of the beam center.

7. A photo-solidification modeling device according to any preceding claim, further including;

   a container for storing the liquid;

   a light source for generating light for solidifying said liquid; and

   a light transmitting means for guiding said light generated by said light source to regions of the liquid.

8. A photo-solidification modeling device for solidifying liquid so as to create a solidified image having a desired three-dimensional shape, comprising:

   a container for storing the liquid;

   a light source for generating light for solidifying the liquid;

   light transmitting means for guiding said light generated by said light source to regions of the liquid;

   a controller for defining a region where said light is to be transmitted;

   means for computing a solidified shape of the liquid at a boundary between the light transmitted region and non-transmitted region; and

   second computing means for calculating an offset quantity for the outermost light transmitted region so as to make a three-dimensional solidified shape at said boundary contact with the desired three-dimensional shape.

9. A photo-solidification modeling device comprising:

   a container for storing a liquid capable of being solidified upon exposure to light;;

   a light source for generating light for solidifying the liquid;

   light transmitting means for guiding said light generated by said light source to regions of the liquid;

   a controller for defining an outermost region of said light transmitted by said light transmitting means;

   means for calculating a shape to be solidified in the liquid at a boundary of said outermost region;

   computing means for calculating an offset quantity so as to make a three-dimensional solidified shape at said outermost region contact with a desired model shape.

10. A photo-solidification modeling device according to any of claims 2 to 9, wherein said light source comprises a laser.

11. A photo-solidification modeling device according to any of claims 2 to 10, wherein said light source comprises an optical fiber device.

12. A photo-solidification modeling device according to any preceding claim, wherein the liquid is a photo-polymer.

13. A photo-solidification modeling method for solidifying liquid so as to create a solidified image having a desired three-dimensional shape, comprising the steps of:

   generating light for solidifying th liquid;

   guiding the light to regions of the liquid;

   defining a region of the liquid to which the light is to be transmitted;

   computing a solidified shape of the liquid at a boundary between a light transmitted region and a non-transmitted region;

   calculating an offset quantity for the outermost light transmitted region; and

   exposing the liquid to the light in accordance with the offset quantity to make a three-dimensional solidified shape at the boundary contact with the desired three-dimensional shape.

14. A high-precision photo-solidification modeling method for forming a solidified three-dimensional object having a shape corresponding to a desired three-dimensional model shape including an inwardly-sloping outer model contour by exposing to light selected regions of a liquid capable of being solidified by exposure to the light to form the desired three-dimensional object comprising the steps of:

   representing the desired three-dimensional model shape by a plurality of sets of light beam coordinates; and

   computing a corresponding plurality of sets of light beam offset exposure coordinates defining regions of the liquid to be exposed to light to form the three-dimensional object with an inwardly-sloping outer contour corresponding to the inwardly-sloping outer model contour of the three-dimensional model.

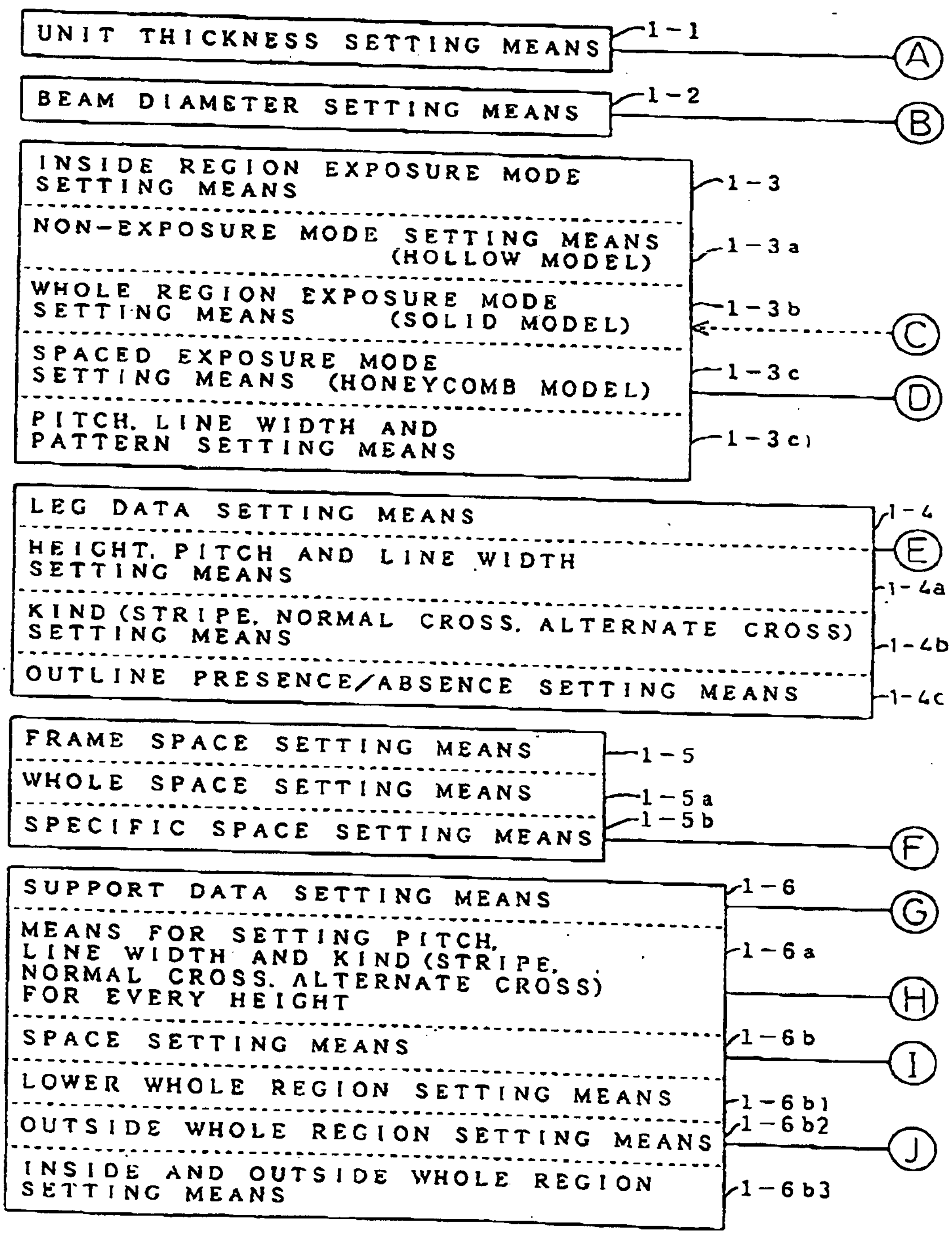
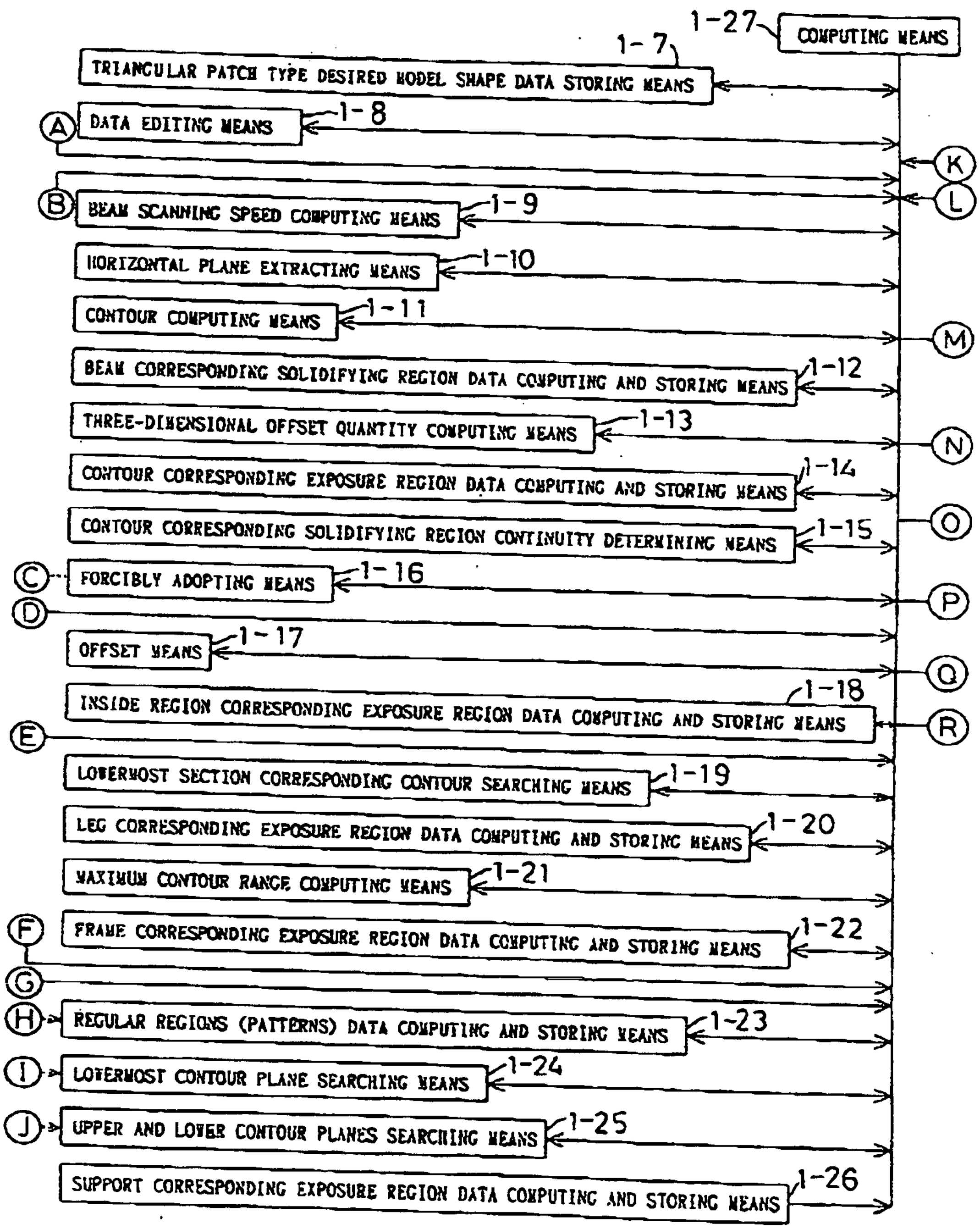

UNIT THICKNESS SETTING MEANS
1-1
A
BEAM DIAMETER SETTING MEANS
1-2
B
INSIDE REGION EXPOSURE MODE SETTING MEANS
1-3
NON-EXPOSURE MODE SETTING MEANS (HOLLOW MODEL)
1-3a
WHOLE REGION EXPOSURE MODE SETTING MEANS (SOLID MODEL)
1-3b
C
SPACED EXPOSURE MODE SETTING MEANS (HONEYCOMB MODEL)
1-3c
D
PITCH, LINE WIDTH AND PATTERN SETTING MEANS
1-3c1
LEG DATA SETTING MEANS
1-4
E
HEIGHT, PITCH AND LINE WIDTH SETTING MEANS
1-4a
KIND (STRIPE, NORMAL CROSS, ALTERNATE CROSS) SETTING MEANS
1-4b
OUTLINE PRESENCE/ABSENCE SETTING MEANS
1-4c
FRAME SPACE SETTING MEANS
1-5
WHOLE SPACE SETTING MEANS
1-5a
SPECIFIC SPACE SETTING MEANS
1-5b
F
SUPPORT DATA SETTING MEANS
1-6
G
MEANS FOR SETTING PITCH, LINE WIDTH AND KIND (STRIPE, NORMAL CROSS, ALTERNATE CROSS) FOR EVERY HEIGHT
1-6a
H
SPACE SETTING MEANS
1-6b
I
LOWER WHOLE REGION SETTING MEANS
1-6b1
OUTSIDE WHOLE REGION SETTING MEANS
1-6b2
J
INSIDE AND OUTSIDE WHOLE REGION SETTING MEANS
1-6b3

FIG. 1(A)



COMPUTING MEANS
1-27
1-7
TRIANGULAR PATCH TYPE DESIRED MODEL SHAPE DATA STORING MEANS
DATA EDITING MEANS
1-8
A
K
B
L
BEAM SCANNING SPEED COMPUTING MEANS
1-9
HORIZONTAL PLANE EXTRACTING MEANS
1-10
CONTOUR COMPUTING MEANS
1-11
M
BEAM CORRESPONDING SOLIDIFYING REGION DATA COMPUTING AND STORING MEANS
1-12
THREE-DIMENSIONAL OFFSET QUANTITY COMPUTING MEANS
1-13
N
CONTOUR CORRESPONDING EXPOSURE REGION DATA COMPUTING AND STORING MEANS
1-14
O
CONTOUR CORRESPONDING SOLIDIFYING REGION CONTINUITY DETERMINING MEANS
1-15
C
FORCIBLY ADOPTING MEANS
1-16
P
D
OFFSET MEANS
1-17
Q
INSIDE REGION CORRESPONDING EXPOSURE REGION DATA COMPUTING AND STORING MEANS
1-18
R
E
LOWERMOST SECTION CORRESPONDING CONTOUR SEARCHING MEANS
1-19
LEG CORRESPONDING EXPOSURE REGION DATA COMPUTING AND STORING MEANS
1-20
MAXIMUM CONTOUR RANGE COMPUTING MEANS
1-21
F
FRAME CORRESPONDING EXPOSURE REGION DATA COMPUTING AND STORING MEANS
1-22
G
H
REGULAR REGIONS (PATTERNS) DATA COMPUTING AND STORING MEANS
1-23
I
LOWERMOST CONTOUR PLANE SEARCHING MEANS
1-24
J
UPPER AND LOWER CONTOUR PLANES SEARCHING MEANS
1-25
SUPPORT CORRESPONDING EXPOSURE REGION DATA COMPUTING AND STORING MEANS
1-26

FIG. 1(B)

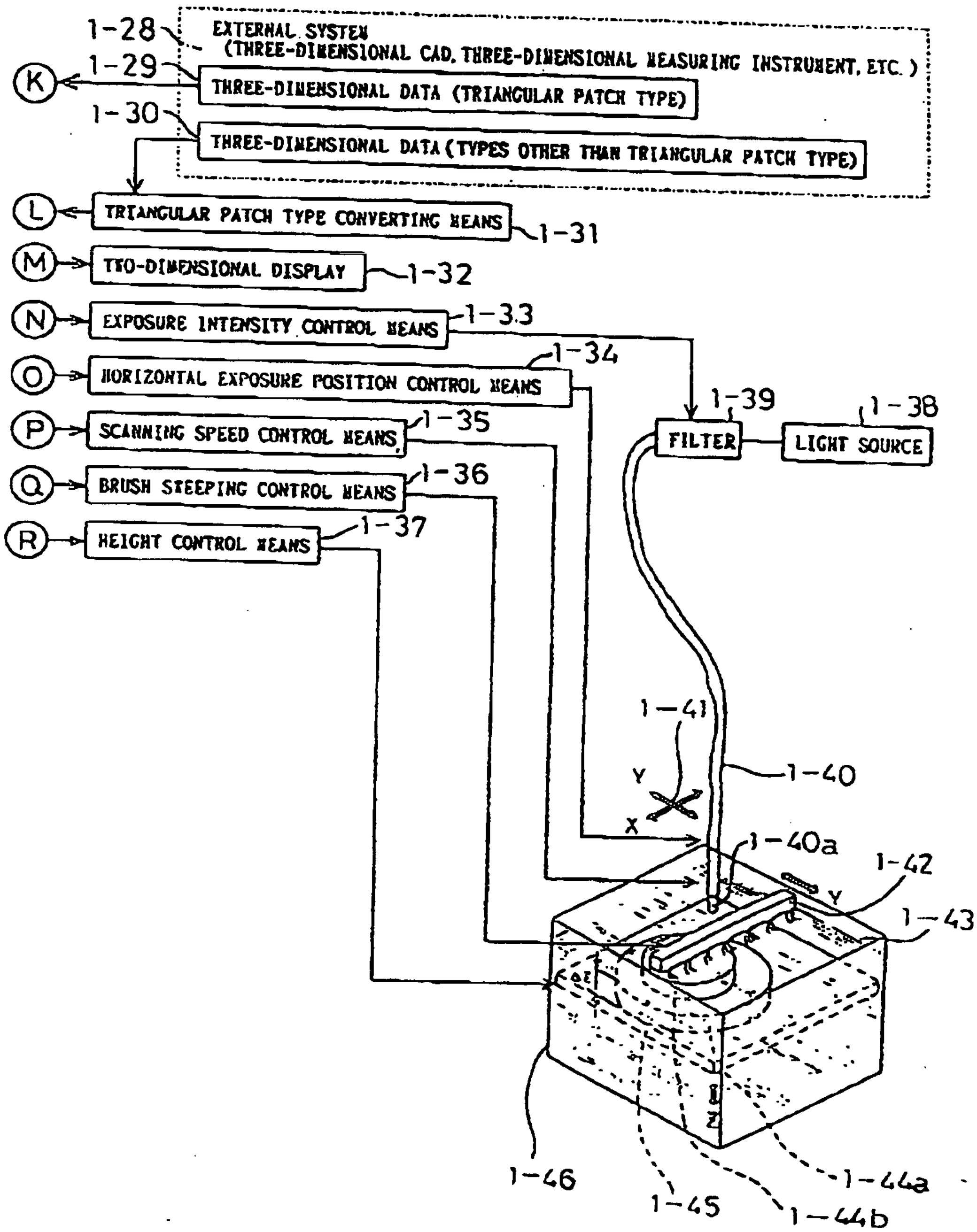
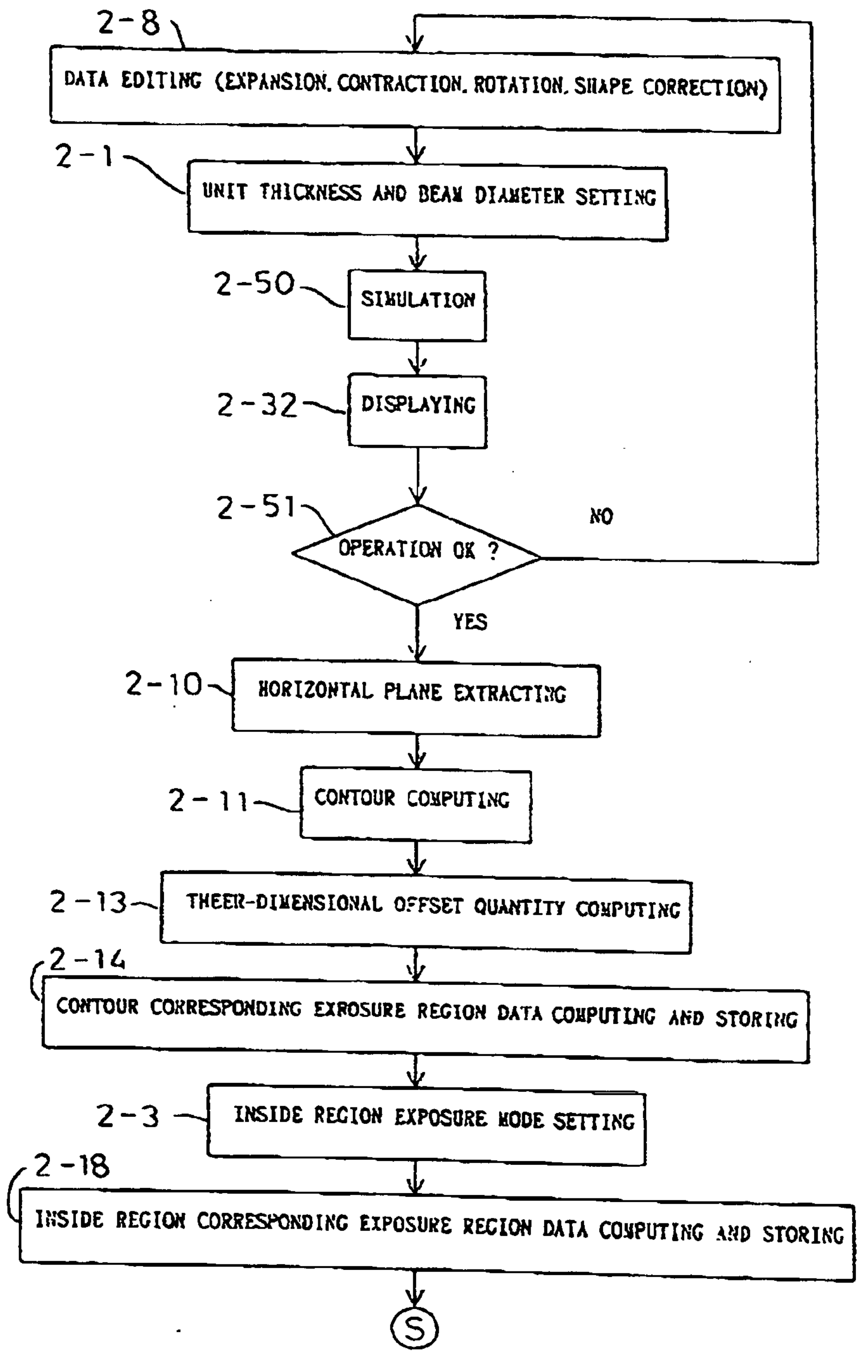

1-28
EXTERNAL SYSTEM
(THREE-DIMENSIONAL CAD, THREE-DIMENSIONAL MEASURING INSTRUMENT, ETC.)
1-29
K
THREE-DIMENSIONAL DATA (TRIANGULAR PATCH TYPE)
1-30
THREE-DIMENSIONAL DATA (TYPES OTHER THAN TRIANGULAR PATCH TYPE)
L
TRIANGULAR PATCH TYPE CONVERTING MEANS
1-31
M
TWO-DIMENSIONAL DISPLAY
1-32
N
EXPOSURE INTENSITY CONTROL MEANS
1-33
O
HORIZONTAL EXPOSURE POSITION CONTROL MEANS
1-34
P
SCANNING SPEED CONTROL MEANS
1-35
Q
BRUSH SWEEPING CONTROL MEANS
1-36
R
HEIGHT CONTROL MEANS
1-37
1-39
FILTER
1-38
LIGHT SOURCE
1-41
Y
X
1-40
1-40a
1-42
Y
1-43
Z
1-46
1-45
1-44a
1-44b

FIG. 1(C)



2-8
DATA EDITING (EXPANSION, CONTRACTION, ROTATION, SHAPE CORRECTION)
2-1
UNIT THICKNESS AND BEAM DIAMETER SETTING
2-50
SIMULATION
2-32
DISPLAYING
2-51
OPERATION OK ?
NO
YES
2-10
HORIZONTAL PLANE EXTRACTING
2-11
CONTOUR COMPUTING
2-13
THEER-DIMENSIONAL OFFSET QUANTITY COMPUTING
2-14
CONTOUR CORRESPONDING EXROSURE REGION DATA COMPUTING AND STORING
2-3
INSIDE REGION EXPOSURE MODE SETTING
2-18
INSIDE REGION CORRESPONDING EXPOSURE REGION DATA COMPUTING AND STORING
S

FIG. 2(A)

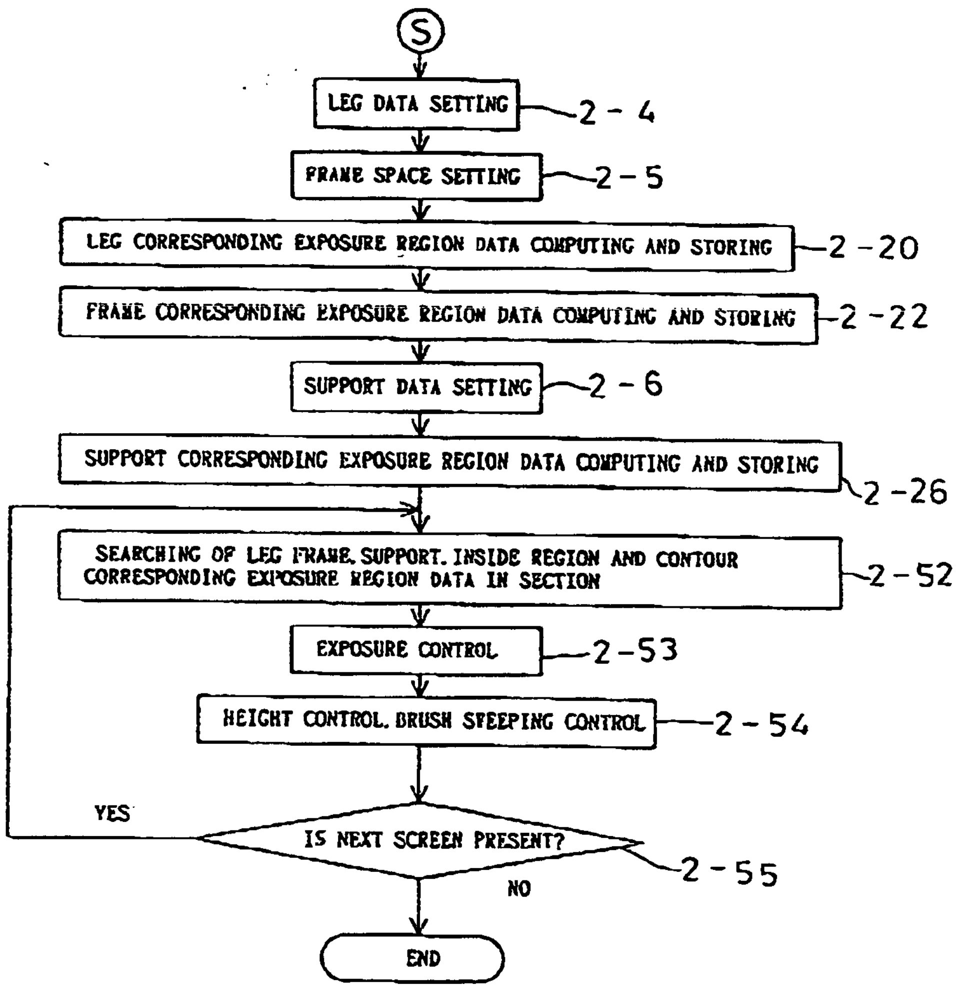

S
LEG DATA SETTING
2-4
FRAME SPACE SETTING
2-5
LEG CORRESPONDING EXPOSURE REGION DATA COMPUTING AND STORING
2-20
FRAME CORRESPONDING EXPOSURE REGION DATA COMPUTING AND STORING
2-22
SUPPORT DATA SETTING
2-6
SUPPORT CORRESPONDING EXPOSURE REGION DATA COMPUTING AND STORING
2-26
SEARCHING OF LEG FRAME, SUPPORT, INSIDE REGION AND CONTOUR CORRESPONDING EXPOSURE REGION DATA IN SECTION
2-52
EXPOSURE CONTROL
2-53
HEIGHT CONTROL, BRUSH SWEEPING CONTROL
2-54
YES
IS NEXT SCREEN PRESENT?
2-55
NO
END

FIG. 2(B)

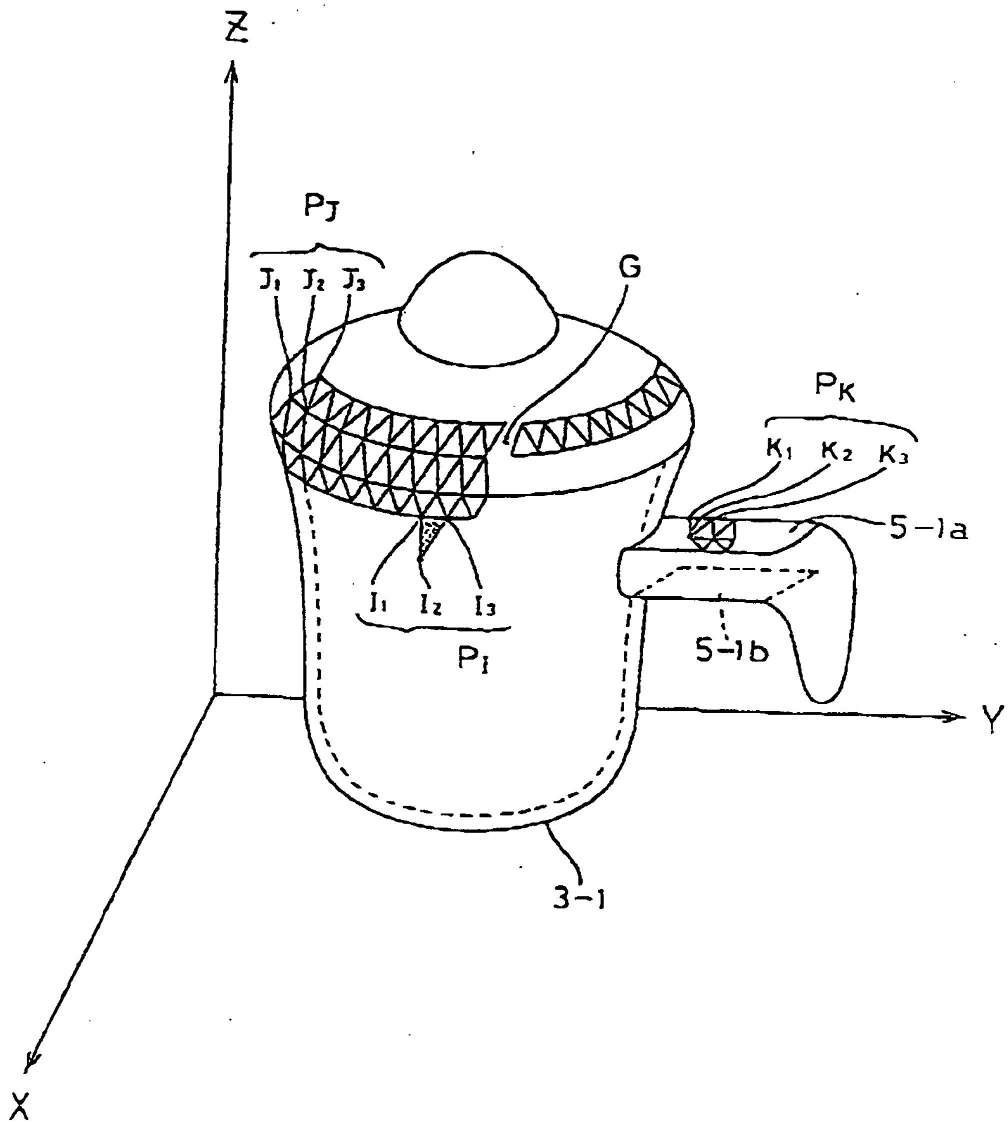


FIG. 3

PATCH NUMBER	FIRST VERTEX COORDINATE	SECOND VERTEX COORDINATE	THIRD VERTEX COORDINATE
P0	⋮	⋮	⋮
⋮			
P1			
⋮	⋮	⋮	⋮
PI	XI1. YI1. ZI1	XI2. YI2. ZI2	XI3. YI3. ZI3
⋮	⋮	⋮	⋮
PJ	XJ1. YJ1. ZJ1	XJ2. YJ2. ZJ2	XJ3. YJ3. ZJ3
⋮	⋮	⋮	⋮
PK	XK1. YK1. ZK1	XK2. YK2. ZK2	XK3. YK3. ZK3
⋮	⋮	⋮	⋮
PN	XN1. YN1. ZN1	XN2. YN2. ZN2	XN3. YN3. ZN3

FIG. 4

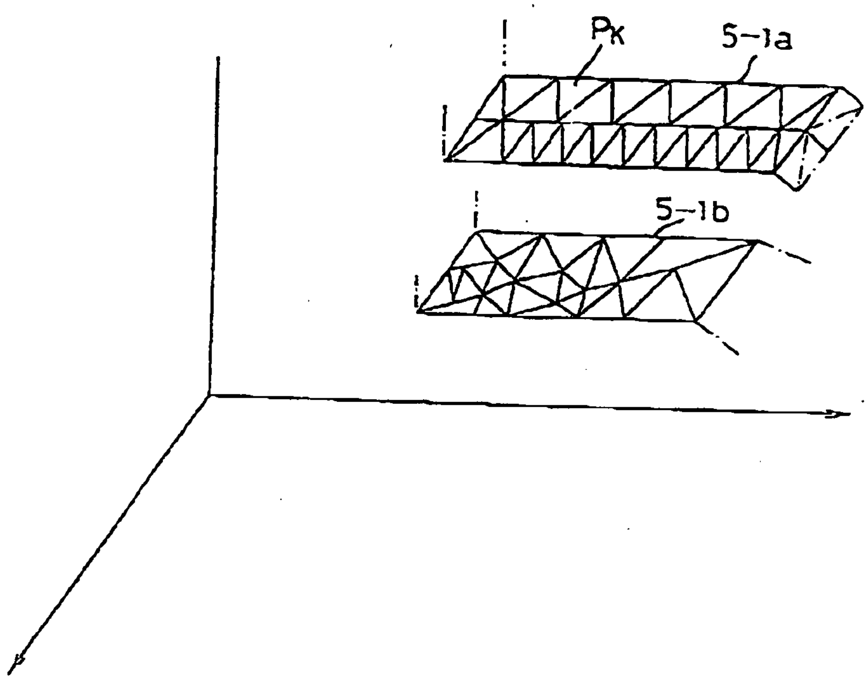


FIG. 5(A)

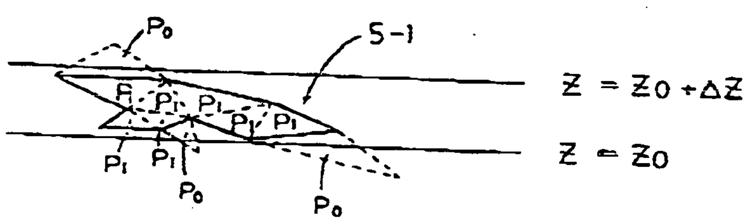


FIG. 5(B)

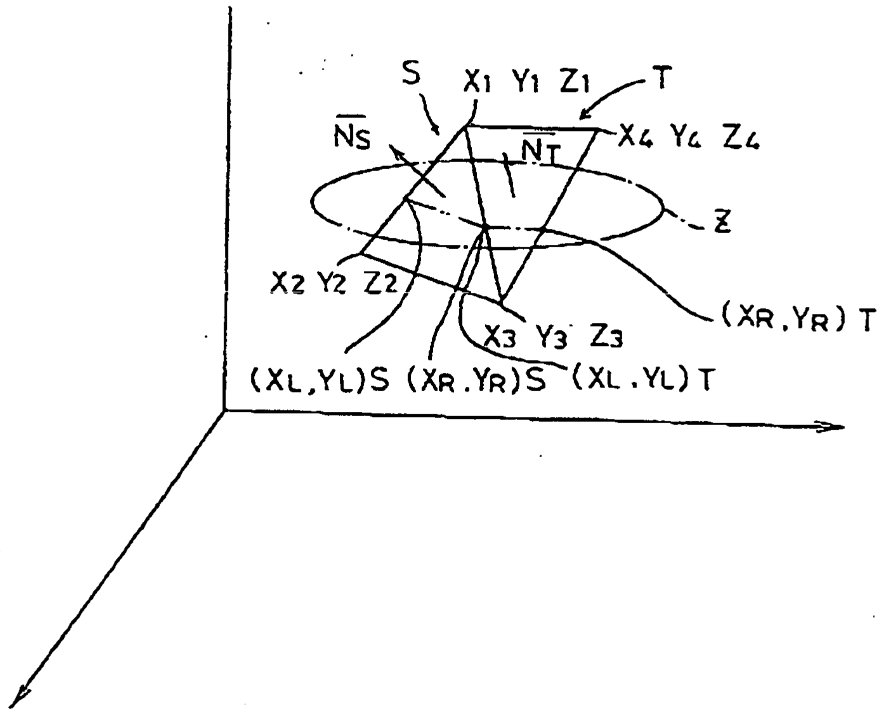

S
X1 Y1 Z1
T
Ns
NT
X4 Y4 Z4
Z
X2 Y2 Z2
(XR,YR) T
X3 Y3 Z3
(XL,YL)S (XR,YR)S (XL,YL) T

FIG. 6

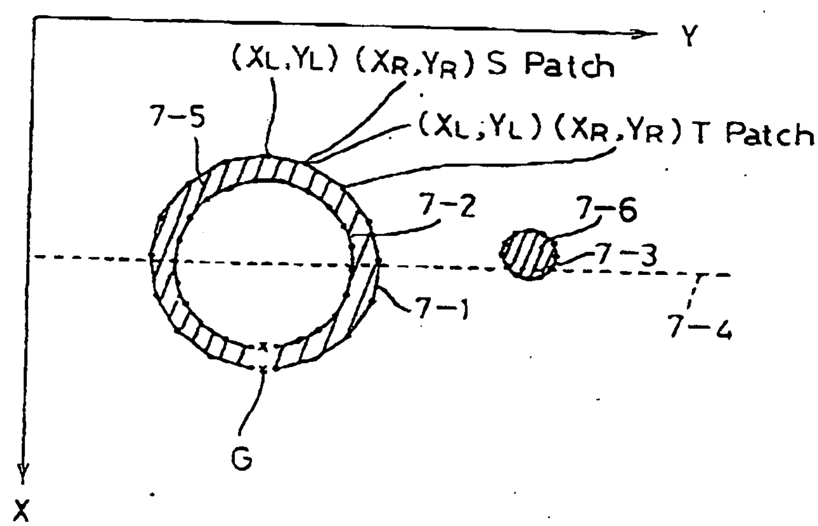

Y
(XL,YL) (XR,YR) S Patch
7-5
(XL;YL) (XR,YR) T Patch
7-2
7-6
7-3
7-1
7-4
G
X

FIG. 7

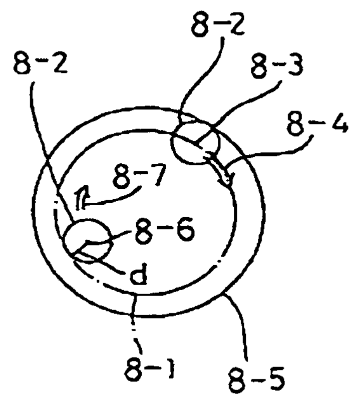


FIG. 8(A)

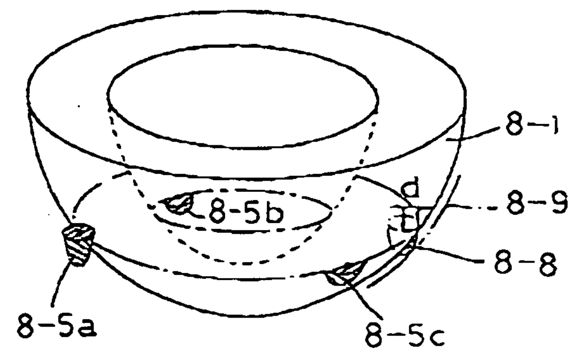


FIG. 8(B)

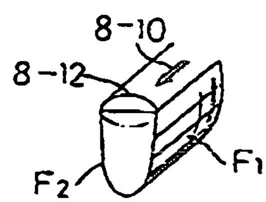


FIG. 8(C)

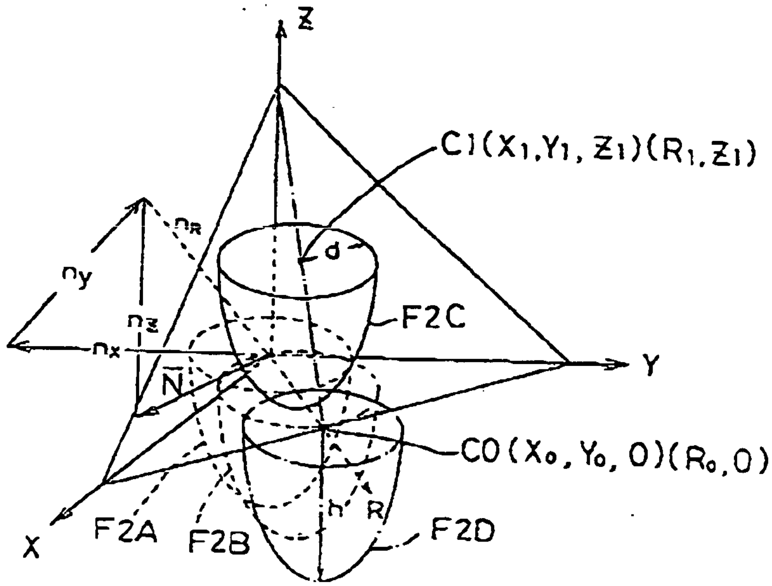

Z
C1(X1,Y1,Z1)(R1,Z1)
nR
ny
d
nz
F2C
nx
Y
N
C0(X0,Y0,0)(R0,0)
h
R
X
F2A
F2B
F2D

FIG. 9(A)

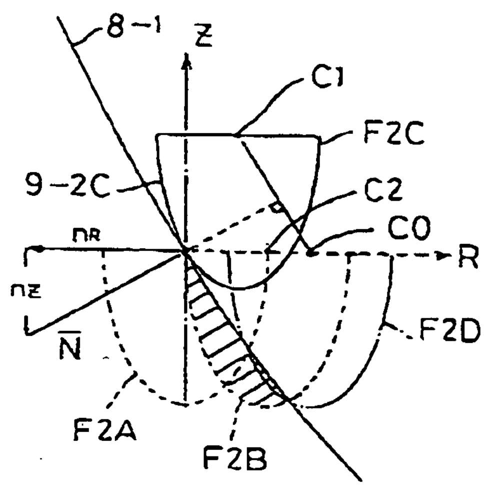

8-1
Z
C1
F2C
9-2C
C2
nR
C0
R
nz
F2D
N
F2A
F2B

FIG. 9(B)

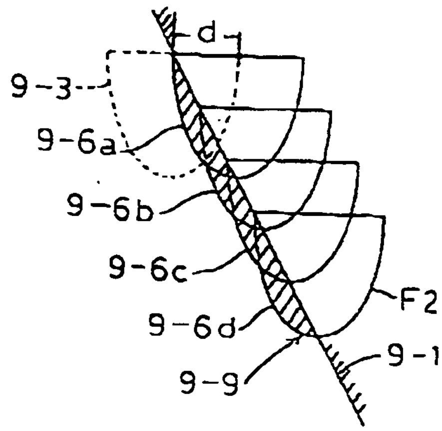


FIG. 9(C)

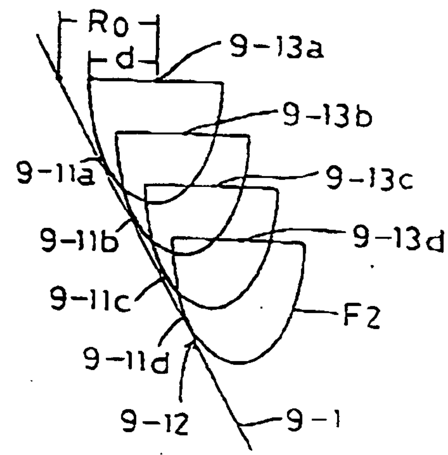


FIG. 9(D)

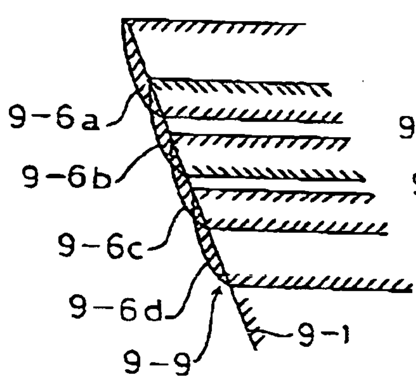


FIG. 9(E)

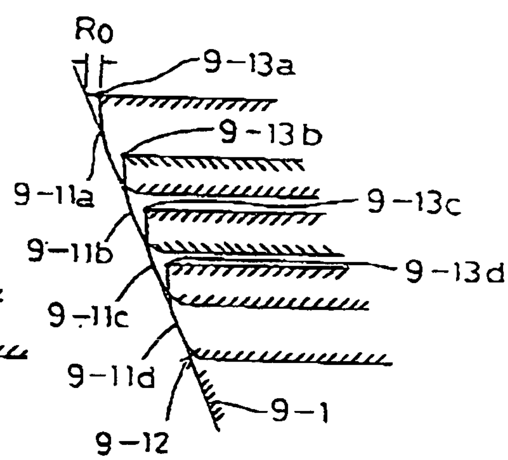


FIG. 9(F)

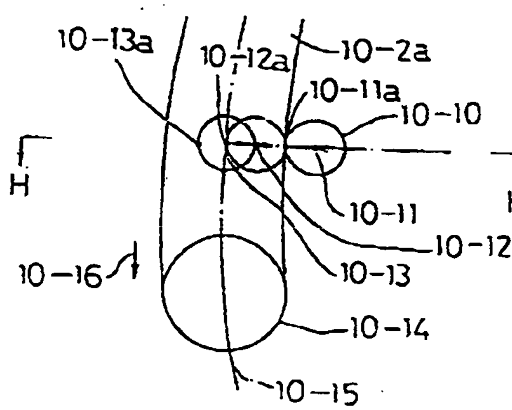


FIG. 10(G)

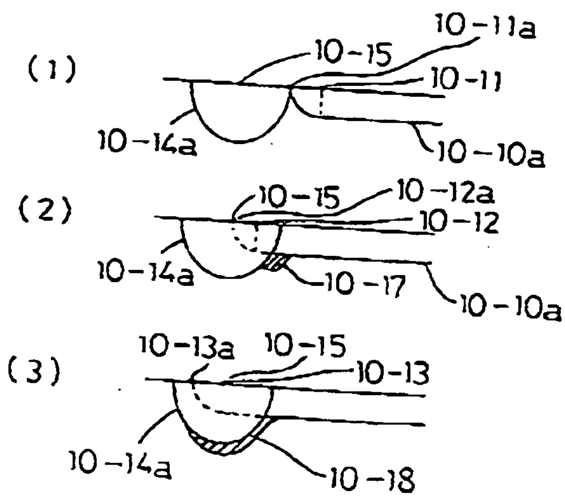


FIG. 10(H)

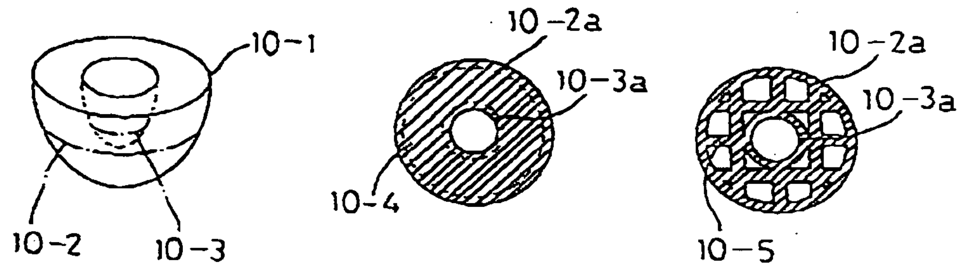


FIG.10(A) FIG.10(B) FIG.10(C)

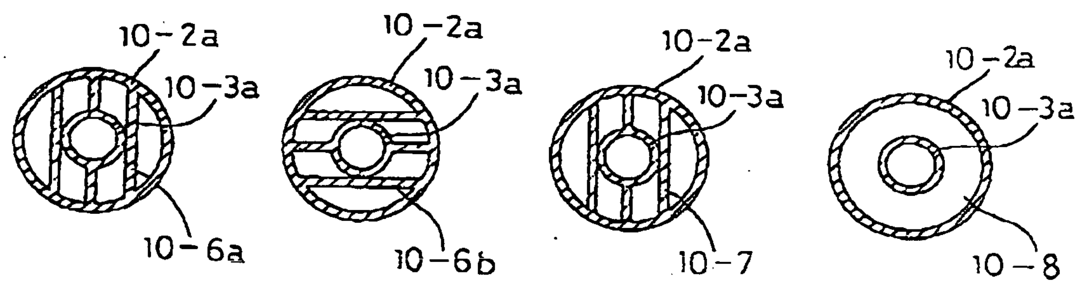


FIG.10(D)1 FIG.10(D)2 FIG.10(E) FIG.10(F)

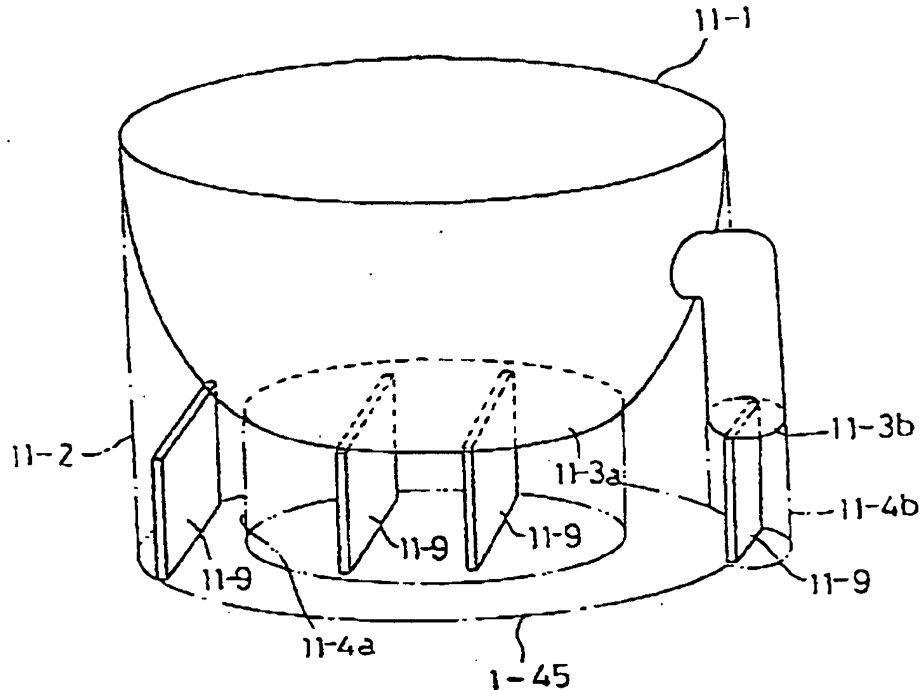


FIG.11(A)

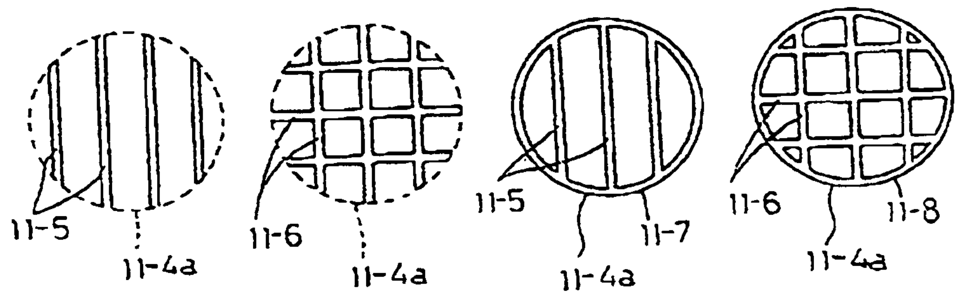


FIG.11(B) FIG.11(C) FIG.11(D) FIG.11(E)

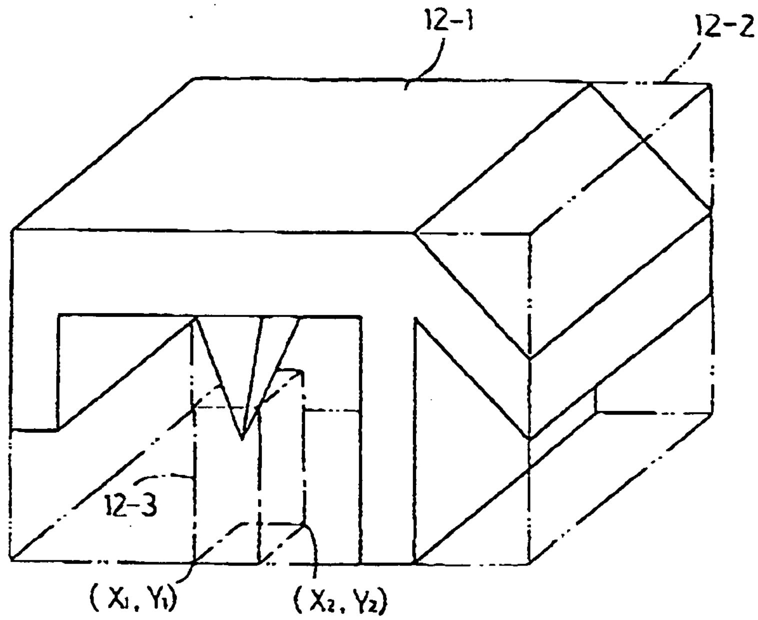


FIG.12(A)

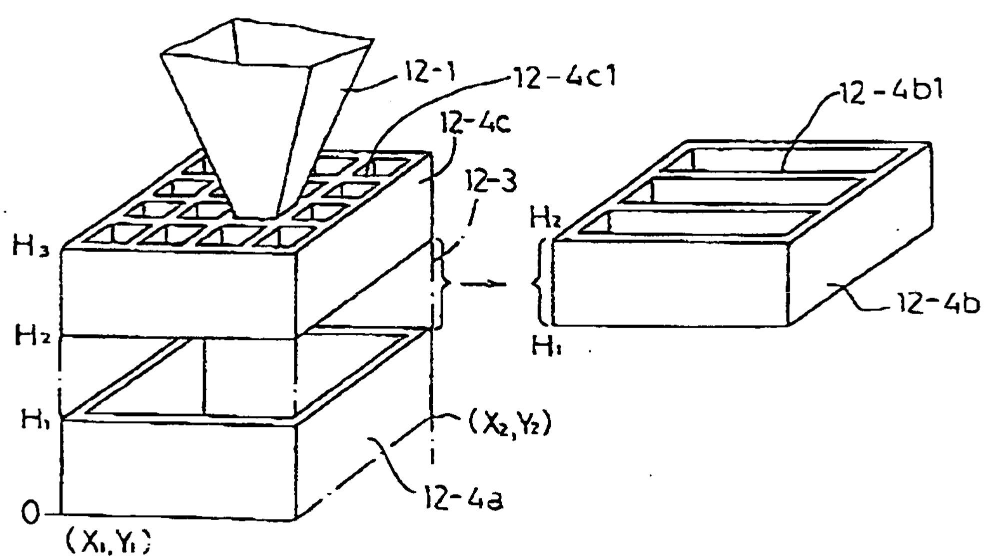


FIG.12(B)

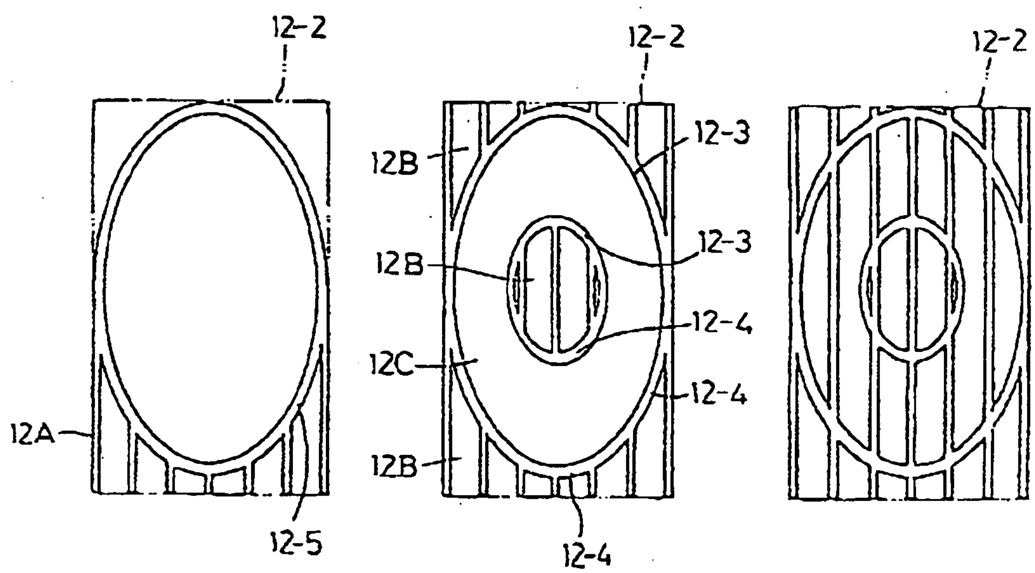


FIG.13(A) FIG.13(B) FIG.13(C)

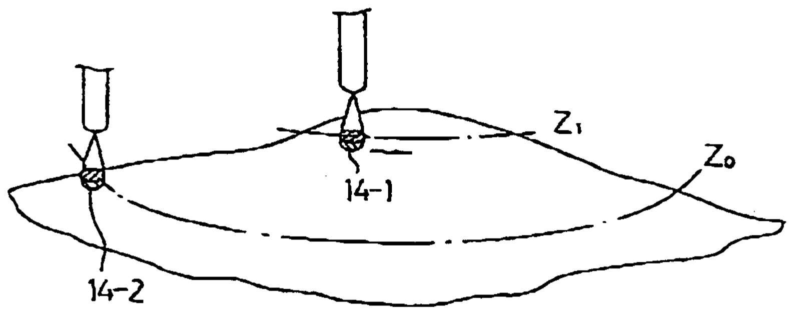


FIG.14(A)

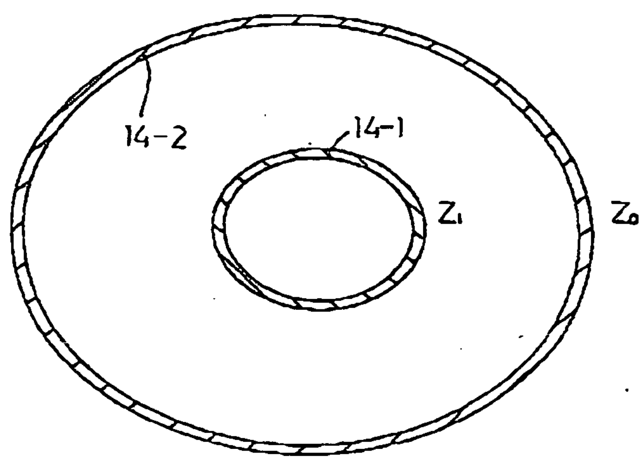


FIG.14(B)

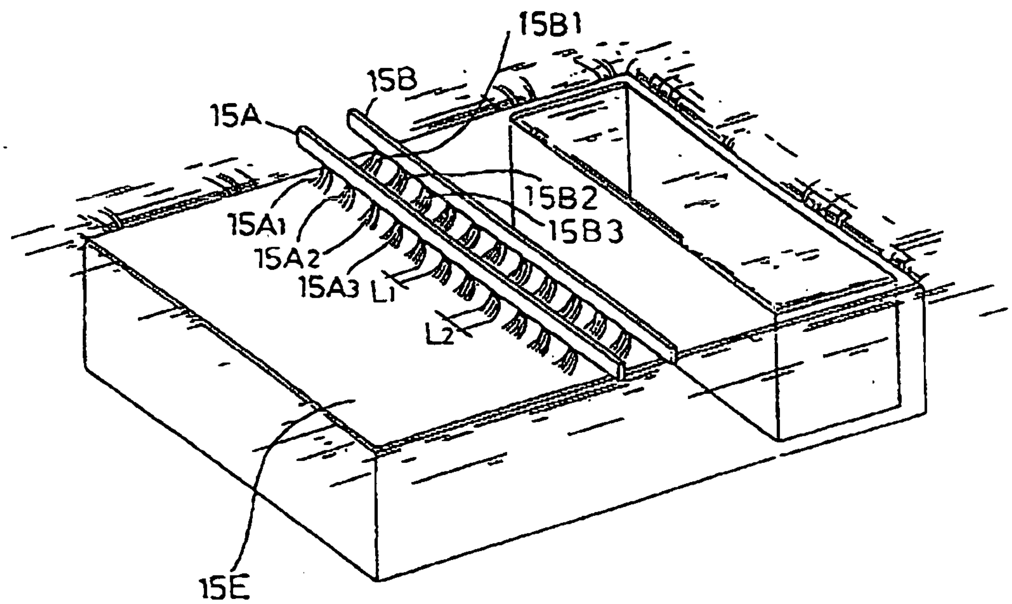


FIG.15(A)

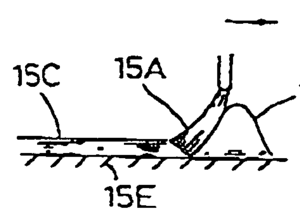


FIG.15(B)

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 91 31 0137

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X,P	EP-A-0 406 513 (MITSUI ENGINEERING & SHIPBUILDING CO LTD) * claim 2; figures 1,7 *	1-3,6-14	B29C67/00 B29C39/42
X,P	EP-A-0 429 196 (3D SYSTEMS INC.) * claim 1; figure 9A *	1-3,6-14	
X	EP-A-0 388 129 (SONY CORPORATION) * claim 1; figures 6A,6B *	1-3,6-14	
X	WO-A-8 910 256 (3D SYSTEMS INC.) * claims 13,15,67,79; figure 26A *	1-3,6-14	
A	PATENT ABSTRACTS OF JAPAN vol. 10, no. 301 (M-525)(2357) 14 October 1986 & JP-A-61 114 818 (FUJITSU LTD) 2 June 1986 * abstract *	1-14	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

B29C

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	11 FEBRUARY 1992	KIRSTEN K.R.M.

CATEGORY OF CITED DOCUMENTS

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Y : particularly relevant if combined with another document of the same category
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P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document